

THE CFB SUMMERSIDE PROJECT
ASPEN SIMULATION

Final Report Submitted to:

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March 1986

DSS File # 25ST.23440-4-9044

53 pp

MICROMEDIA

EXECUTIVE SUMMARY

A techno-economic study of the utilization of Eastern Canadian coal in steam production, using Atmospheric Fluidized Bed Combustion (AFBC), is presented here. The industrial scale AFBC boiler, located at Summerside PEI, Canada, was modelled using the process simulator ASPEN (Advanced System for Process Engineering). The unit's normal operating conditions are:

- 17 000 kg/hr of 1 070 kPa steam produced
- carbon burnout 97.46%
- combustion air flow 23 770 kg/hr
- bed temperature 870°C
- limestone flow 524 kg/hr
- mass-median particle diameter 1.4 mm
- coal flow 1 910 kg/hr
- as-received moisture content 7.95%
- ash content 13.03%,
- carbon content 62.78%
- mass-median particle diameter 7.6 mm

Using the ASPEN model, the carbon burnout efficiency of the process was studied under the following conditions:

- combustion air flow 16 360--27 480 kg/hr
- bed temperature 815°C--927°C
- limestone flow 262--786 kg/hr
- mass-median particle diameter 0.97--1.88 mm
- coal flow 1 432--2 386 kg/hr
- as-received moisture content 5.7--10.1%
- ash content 8.7--17.0%
- carbon content 56.6--67.4%
- mass-median particle diameter 5.6--9.6 mm

The relative economics of this process vs. electric heating in Eastern Canada (nominal case: coal cost C\$25/Ton, limestone cost C\$36/Ton, electricity cost C\$0.085/kW-hr), was studied over the following ranges: coal cost C\$12.5--C\$37.5/Ton, limestone cost C\$18--C\$54/Ton and electricity cost C\$0.0425--C\$0.1275/kW-hr.

Predictions from the ASPEN model compared very well with actual plant data. Steam flowrate predictions were within 10% of plant measurements.

The operational sensitivity analysis over the stated ranges shows that the combustion air flowrate has the greatest effect on the predicted carbon burnout. Carbon burnouts ranged from 93.03% at an air flowrate of 27 480 kg/hr to 99.47% at an air flowrate of 16 360 kg/hr.

The total capital required to build the plant was found to be 27 million late 1985 Canadian dollars. The net present value of the yearly benefits obtained over the 25 year plant lifetime is predicted to be 65 million late 1985 Canadian dollars. The economic sensitivity analysis shows that the plant's economic viability vs. electric heating is very sensitive to

the price of the electricity. Rising electricity prices make this plant more attractive.

ASPEN was shown to be an excellent tool for the simulation and technoeconomic evaluation of AFBC processes. Now that the model is built and available, its use to answer "what-if" questions should be exploited.

SOMMAIRE

Nous présentons ici une étude technico-économique sur l'utilisation du charbon de l'est canadien par la génération de vapeur par Combustion Atmosphérique dans un Lit Fluidisé (Atmospheric Fluidized Bed Combustion), AFBC. La bouilloire à l'échelle industrielle de Summerside, IPE, Canada a été modelisée grâce au simulateur de procédés ASPEN (Advanced System for Process Engineering - Système Avancé pour le Génie des Procédés). Les conditions d'opérations normales à ce site sont:

- Production de vapeur à 1070 kPa 17,000 kg/hre
- Carbone consommé à 97.46 %
- Débit d'air pour la combustion 23,770 kg/hre
- Température du lit 870 °C
- Débit de pierre à chaux 524 kg/hre
- Diamètre moyen des particules sur une base massique 1.4 mm
- Débit de charbon 1,910 kg/hre
- Humidité initiale 7.95 %
- Contenu en cendres 13.03 %
- Contenu en charbon 62.78 %
- Diamètre moyen des particules sur une base massique 7.6 mm

A l'aide du model d'ASPEN, l'efficacité de consommation du carbone pour ce procédé a été déterminée pour les conditions

suivantes:

- Débit d'air pour la combustion 16,360--27,480 kg/hre
- Température du lit 815 °C--927 °C
- Débit de pierre à chaux 262--786 kg/hre
- Diamètre moyen des particules sur une base massique 0.97--1.88 mm
- Débit de charbon 1,432--2,386 kg/hre
- Humidité initiale 5.7--10.1 %
- Contenu en cendres 8.7--17.0 %
- Contenu en charbon 56.6--67.4 %
- Diamètre moyen des particules sur une base massique 5.6--9.6 mm

Le rendement économique de ce procédé comparativement au chauffage électrique pour la région de l'est canadien (données de base: coût du charbon \$25/T., coût de la pierre à chaux \$36/T., coût de l'électricité \$0.085/kW·hre) a été étudié pour les gammes de valeurs suivantes: coût du charbon \$12.5--\$37.5/T., coût de la pierre à chaux \$18--\$54/T., coût de l'électricité \$0.0425--\$0.1275/kg·hre.

Les prédictions du modèle d'ASPEN se sont avérées en excellent accord avec les données d'opération de l'usine. L'erreur sur les débits de vapeur ainsi calculés n'a pas excédé 10 %.

L'analyse de sensibilité aux données techniques dans les gammes citées précédemment a montré que c'est le débit d'air qui influence le plus fortement l'efficacité d'utilisation du

carbone. Ces efficacités varient de 93.03 % pour un débit d'air de 27,480 kg/hre à 99.47 % pour 16,360 kg/hre. L'investissement capital total requis pour la construction de l'usine a été estimé à \$27 MM de la fin de l'année 1985. La valeur présente nette des profits annuels envisagés pour une période de vie économique de 25 ans de ce projet a été calculée comme étant \$65 MM de la fin de l'année 1985. L'analyse de sensibilité économique pour ce procédé vis-à-vis au chauffage électrique a montré que sa viabilité économique est très sensible au prix de l'électricité. La montée actuelle du prix de l'électricité rend donc ce projet plus attrayant.

Nous avons montré qu'ASPEN constitue un excellent outil pour la simulation et l'analyse technico-économique des procédés AFBC. Maintenant qu'un modèle fiable existe et est disponible, on peut explorer des situations inaccessibles jusqu'à présent.

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1.0 INTRODUCTION

In the 1970's the government of Canada recognized that Eastern Canada's consumption of expensive imported oil would be lessened if its large reserves of high sulfur coal were utilized in an environmentally safe manner.

At that time a promising technology becoming commercially available outside Canada was Atmospheric Fluidized Bed Combustion (AFBC). While the process of fluidization, wherein reacting solids are held in suspension by an upwardly flowing fluid, was not new, the use of this process to burn coal for energy production was. It was also found that by feeding limestone into the reactor with the coal and holding the reaction temperature around 870°C (1600°F), the emissions of sulfur dioxide could be greatly reduced.

To introduce this technology to Canada and to demonstrate it on an industrial scale the Government decided to have a Canadian contractor build two commercial scale, steam raising, Atmospheric Fluidized Bed Boilers which would burn high-sulfur, high-ash Eastern Canadian coals. To control pollution a local maritime limestone was specified as the sulfur sorbent.

Two foreign firms, one British and one American, were hired to produce designs for this facility and sub-contract the work to Canadian firms. The American design produced by Foster-Wheeler Boiler Corporation won the

bidding and the construction was sub-contracted to Montreal Engineering Company, Limited.

The boilers were erected at the Canadian Forces Base Summerside, Prince Edward Island. The AFBC units provided, in an environmentally safe and economic manner, most of the heating steam used at CFB Summerside during the 1985 heating season.

Other applications that could utilize the poor quality Eastern Canadian coal include:

- electric power generation stations, (conventional or FBC-based technology)
- steam generating heating plants, (conventional or FBC-based technology)
- combined cycle electric power generation stations
- coal gasification & coal liquefaction plants
- co-processing of coal and bitumen
- chemical feedstock production

Each of these industries must be considered when a new facility is envisioned. Unfortunately, making an enlightened decision is unlikely due to the lack of useful comparative studies. For example, each of the processes used by these industries has been analyzed on a different basis by different people using:

- different thermodynamic data

- different kinetic models
- different unit operation models
- different costing and economic analysis data

To fill this void Queen's University has begun a program of research into the efficient use of coal. The long-term goal of the program is an analysis of the competing combustion technologies using a common simulator which provides increased confidence in the relative difference between the competitors, easy comparison under different modes of operation and easy re-evaluation of processes when data-bases are updated.

The process simulator used in this research program is ASPEN (Advanced System for Process Engineering). It was developed at the Massachusetts Institute of Technology (MIT) under a United States Department of Energy (DOE) contract. ASPEN was designed to simulate coal processes and therefore contains many features essential to this type of work. ASPEN also contains economic analysis and optimization subroutines making it a valuable tool in this research.

Chapter 2 outlines the long term objective of the research program undertaken at Queen's University and the short term goals addressed by this work. Also discussed in this chapter are the past studies of this type and the overall fashion in which this study will be undertaken.

Chapter 3 discusses the CFB Summerside steam heating plant. Here the type of equipment used in the production of the heating steam and the physical layout and connections between this equipment is put forward as process

flowsheets. The capacity of the plant is defined here as well as the operating conditions of the larger pieces of equipment.

Chapter 4 introduces the concept and application of process simulation technology. This chapter also provides a detailed description of the manner in which the CFB Summerside steam heating plant and the process of fluidized bed combustion have been modelled.

Chapter 5 compares the values predicted by the model to actual plant operating data and data from the Foster-Wheeler design manual. Comparisons of heat and material balance predictions, particle size analysis predictions and equipment-sizing results are presented in this section.

Chapter 6 contains the economic analysis data produced by the this study. Here the techniques and data used in the prediction of the capital required and the annual operating expenses incurred by a fluidized bed steam generation plant are presented. Comparisons are made against Summerside data wherever possible.

Chapter 7 presents one of the uses of a process simulation, the sensitivity analysis. Discussed in the chapter is the plant's operational sensitivity, represented as carbon loss, to changes in coal feed, limestone feed and bed operating conditions. The economic sensitivity of the process to changes in coal, limestone or utilities costs is also put forward.

The final chapter is a discussion of the viability, in economic and academic terms, of this type of research.

2.0 OBJECTIVES

The long term objectives of this research program are to develop a common basis for the technical and economic comparison of coal-based energy technologies and to develop optimal strategies for using coal. The short term objective, and the one addressed here, is to demonstrate the technical feasibility of using ASPEN to design FBC-based power plants. This will be done by simulating the CFB Summerside Project. The key results include heat and material balances, equipment sizes, and an economic analysis of the process.

ASPEN has been used in coal conversion simulations in the past. Methanol Synthesis was studied by Schwint (1985) and Knudsen (1982) while Barker (1983) studied the Tri-State Indirect-Liquefaction process. The work that will be of most use to us is the study by Bajura (1982) of Pressurized Fluidized Bed Combustion in electric power generation. In Bajura's work, the ASPEN simulation required the input of combustion efficiency, sulfur capture, solid elutriation rate and the particle size distribution of the elutriated solids. For this work to be useful these properties have to be calculated internally by predictive models of the process.

This requirement prompted a search for a predictive model for the fluidized bed combustion of coal. Many models are available from literature sources, but agreement to within a factor of two between experimental and predicted data even for elutriation, a phenomena that has been studied for many years, has not been attained (Bergougnou and Briens,

1986). Also, some aspects of the process, combustion rate and sulfur capture efficiency for example, are dependant on the type of coal and limestone fed, and the operating condition of the combustor. This suggests that utilization of a model that has not been validated with data from a commercial plant, similar in design to CFB Summerside's boiler and using the same fuel and sorbent, would produce inaccurate predictions. Since no model with these qualifications could be found, a simple AFBC model was developed. A description of the model used for this study and examples of its predictive capabilities are found in section 4.4.1.

3.0 THE CFB SUMMERSIDE STEAM HEATING PLANT

3.1 Introduction

3.2 The Process

3.3 Summary

3.1 INTRODUCTION

At CFB Summerside there are two coal-fired AFBC boilers which together produce 36 000 kg/hr (80000 lb/hr) of 1 070 kPa (155 psia) steam when operating at capacity. This operating rate consumes approximately 5 000 kg (11000 lb) of coal and 2 050 kg (4500 lb) of limestone per hour. These flow rates necessitate a comprehensive system for the reception, storage, preparation and handling of coal, limestone, fly ash and bed residue. Feed water treatment facilities and electrical supply equipment are also required. All of this equipment is housed within the boiler building and will be accounted for in the simulation.

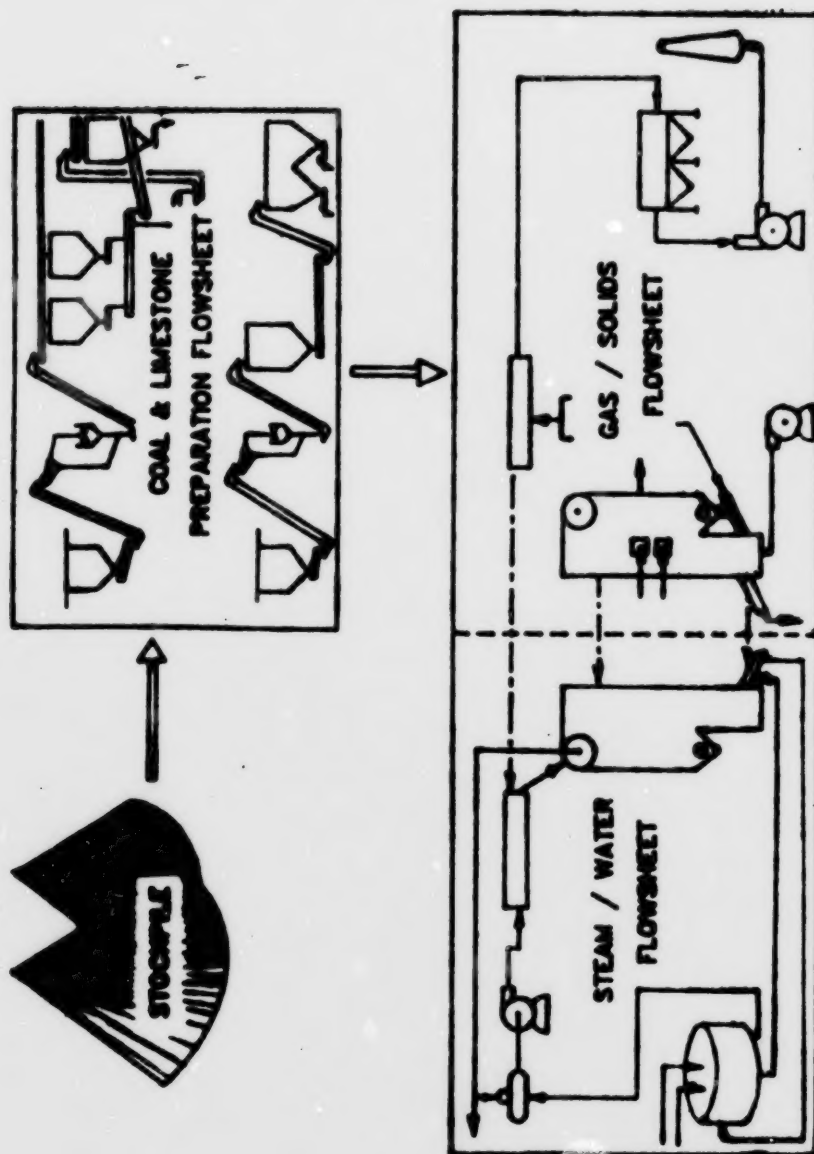
This chapter provides an outline of the physical layout and connectivity of the steam generating plant, the operation of the equipment used and some general observations on the plant's operation and the simulation model.

3.2 THE PROCESS

The plant can be most easily regarded as three separate facilities working as one. These are represented by:

the Coal and Limestone Preparation Flowsheet, the Gas/Solids Flowsheet and the Steam/Water Flowsheet. Figure 1 is a schematic diagram of the

FIGURE 1
Overall Process Flowsheet



overall process showing the three main sections of the plant. A description of the equipment employed and the unit operations that occur within each of the three facilities follows.

The Coal and Limestone Preparation Flowsheet is shown in Figure 2. It should be noted that this system contains equipment to transport solids between storage facilities and classification equipment. Since these transportation devices are assumed not to act on the solids they convey, they will not appear within the ASPEN simulation. The capital cost and the cost of the power required to drive them is, however, included in the economic study.

The coal feeding system, because of out-door stockpiling, must be able to process frozen and/or wet coal. Also, redundant feeding systems were stipulated to eliminate the possibility of the having a plant shut-down due to a failure in one of the transporting devices. To satisfy these two requirements an elaborate coal feeding system was designed. Coal, brought from the stockpile, passes through a large steel grate or "grizzly" to break up any large frozen pieces. Any metal is removed by a magnet before the coal enters a screening and crushing circuit that prepares the coal for feeding to the combustors. All coal leaving this circuit is below 50 mm (2 inches) in diameter, the mean particle diameter being approximately 7.5 mm (.3 inches). A series of back up storage facilities and transportation devices complete the coal feeding system.

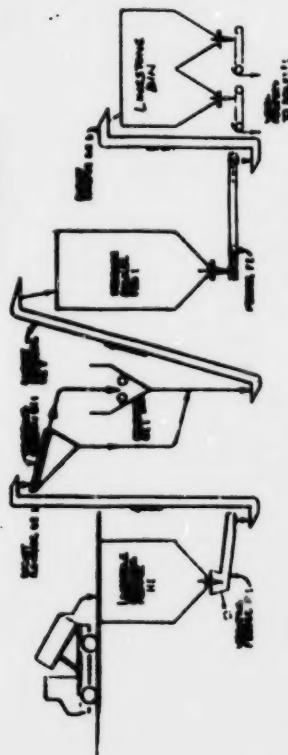
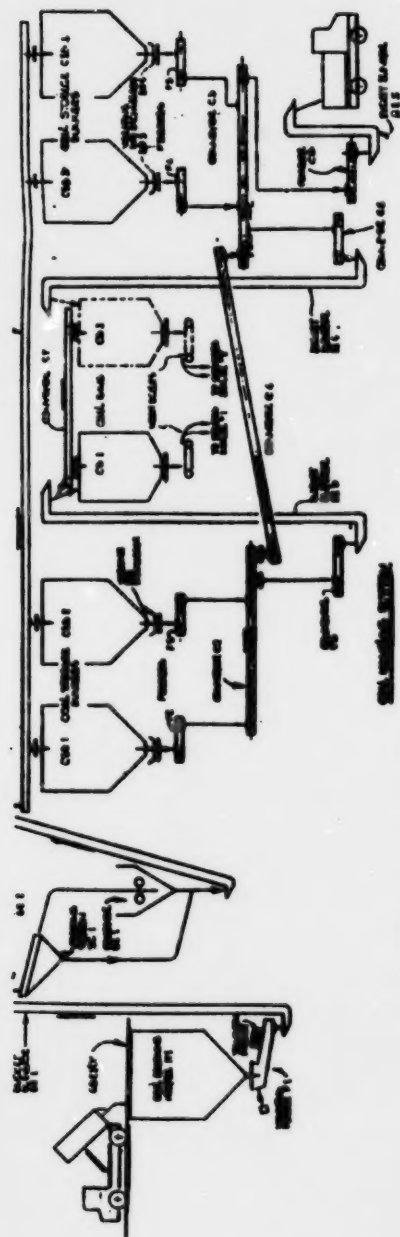


FIGURE 2
CFB Summerside - ASPEN Simulation
Coal and Limestone Preparation
FloorSheet

Double screened limestone arrives at the plant by truck and, because it is pre-processed, passes directly to storage and transportation equipment.

A process flowsheet of the Gas/Solids Flowsheet is shown in Figure 3. The coal and limestone are transported from the "day-bins" to the combustor by remote controlled weigh-feeders. Once inside the combustors the coal and limestone particles are rapidly mixed into a bed of ash and limestone particles that are suspended by an upward flow of combustion air. The bed is controlled at approximately 870°C (1600°F) by water-cooled walls and 18 in-bed cooling tubes. As the coal burns, sulfur dioxide is produced and captured as calcium sulfate by the calcined limestone which makes up the bulk of the bed. Bed height is controlled by two drain pipes and water-cooled screw conveyors ("bed-drain coolers") which are located below the combustors.

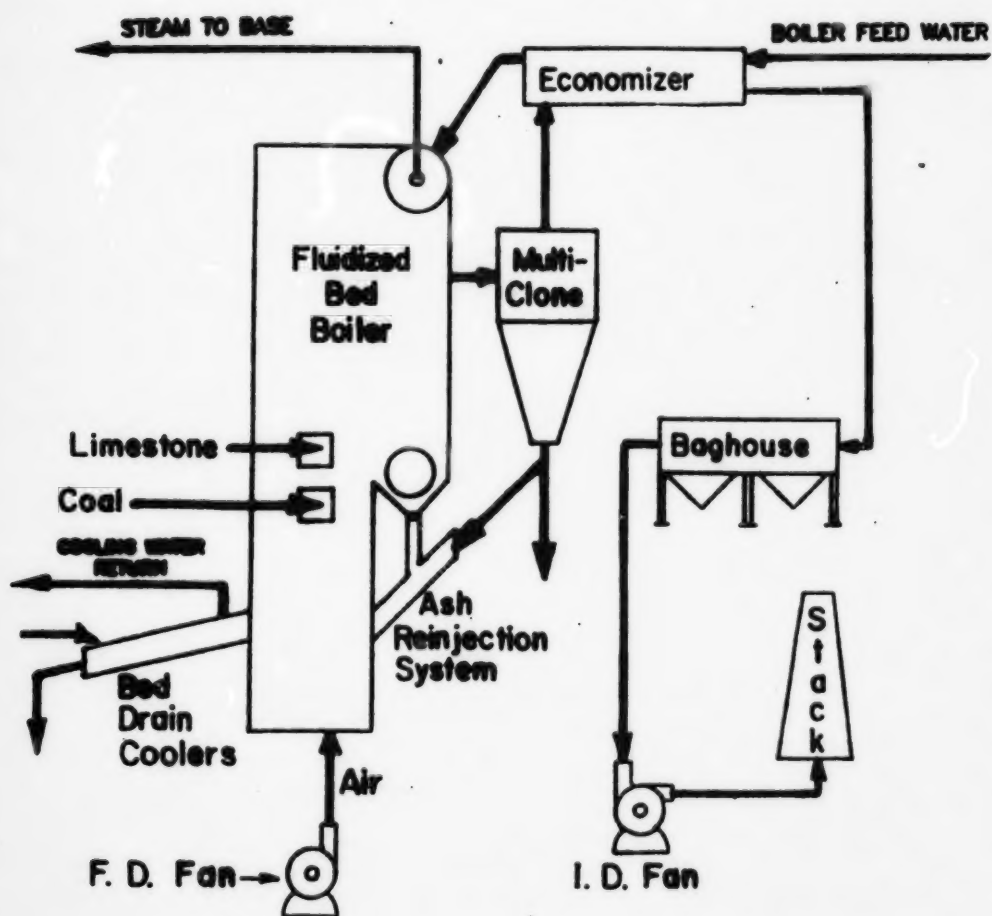
To insure adequate velocity and pressure to elevate the bed particles, the air is passed through huge forced-draft (FD) fans. About 45 000 kg/hr (100000 lb/hr) of air at 3 m/s (10 ft/s) are required by the boilers. The FD fan consumes most of the power required by this plant.

Once through the bed, the air and suspended solids of ash, char and limestone pass through an array of boiler tubes which cool the combustion products to approximately 270°C (520°F).

As the air passes through the bed, the smaller particles are entrained in the gas stream. Only the smallest of these particles are not returned

FIGURE 3
CFB Summerside - ASPEN Simulation

Gas/Solids Process Flowsheet



to the bed by the cyclones through which the combustion gases must pass before leaving the combustors. Once through the cyclones the gases exchange heat with the boiler feed water in economizers. Large induced-draft fans pull the gasses through the economizers and a final particulate cleaning stage, the baghouses.

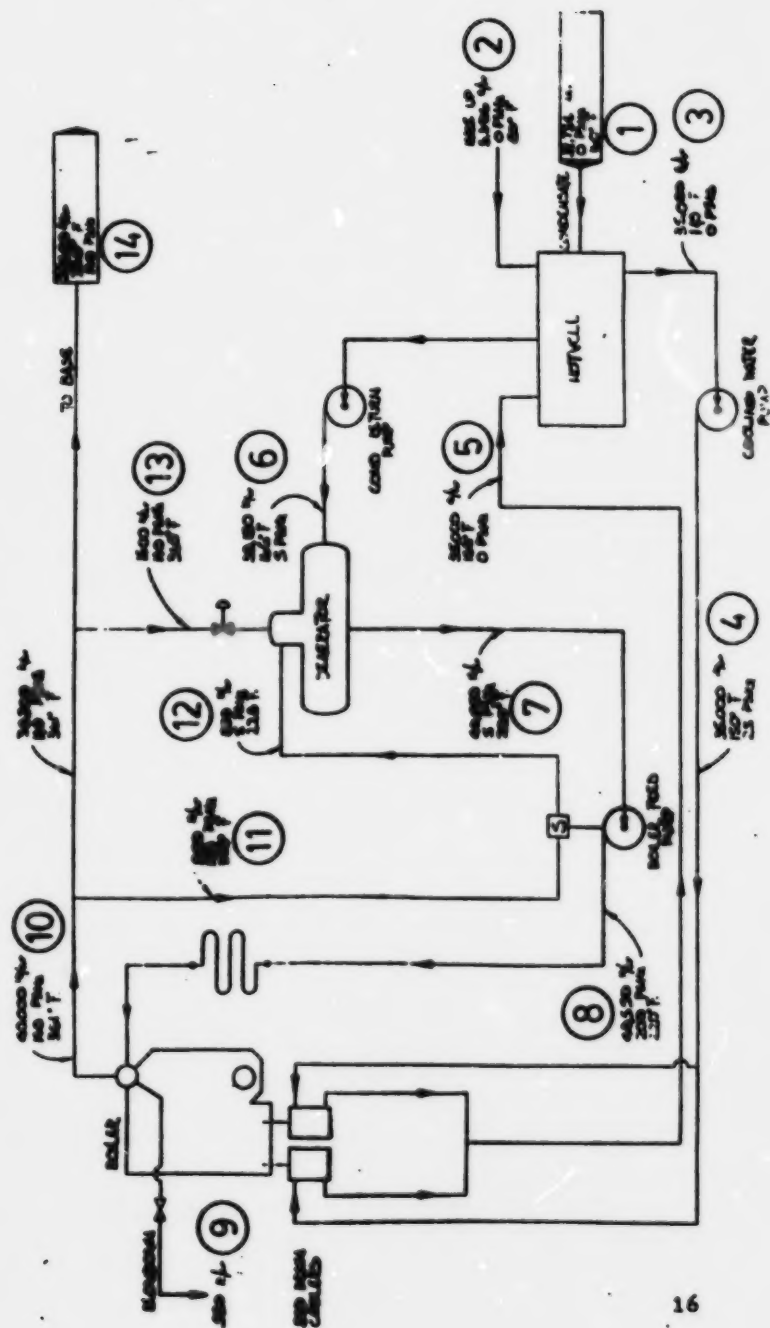
The particulates that are collected by the baghouses are pneumatically transported to a silo within the boiler building. This pneumatic transportation system is not included in the simulation but an approximate cost of the system is included in the economic evaluation of the plant.

A process flowsheet of the the Steam/Water Flowsheet is shown in Figure 4. The condensate returning from the base is supplemented with makeup water and held in a large insulated holding tank called the "hotwell". The "hotwell" is heated by the water that is returning from the bed-drain coolers. Boiler feed water, drawn from the "hotwell" is first passed to a de-aerator, where any air that may have leaked into the system is driven off by "live steam" that is supplied by the boilers. It was planned that at this point the feed water would be pumped up to 1 480 kPa (215 psia) by a steam driven pump to save electricity. Unfortunately this pump polluted the feed water with oil and its backup electric pump is now being used exclusively.

The high pressure water is then fed to the economizer. From there it travels to the steam drum where it flows down into the water-walls or the convection boiler bank and returns as steam. At this point some water (250 kg/hr (550 lb/hr)) is purged into the blowdown tank, with the rest

FIGURE 4

CFB Summerside - ASPEN Simulation Steam/Water Process Flowsheet



heading onward to supply the de-aerator (730 kg/hr (1600 lb/hr)) and the base steam heating network (17 100 kg/hr (37700 lb/hr)).

3.3 SUMMARY

This chapter has provided an overview of the plant and the type of equipment used. Also provided were the operating conditions of the large pieces of equipment and the connectivity of these same pieces. Process flowsheets for the plant were provided in Figures 2,3 and 4.

This is the information that will be used to simulate the plant.

4.0 ASPEN SIMULATION

4.1 Introduction

4.2 Thermodynamic Data - Acquisition and Validation

4.3 Coal and Limestone Preparation Flowsheet

4.4 Gas/Solids Flowsheet

4.4.1 Fluidized Bed Model

4.5 Steam/Water Flowsheet

4.6 Flowsheet Convergence and Control

4.7 Summary

4.1 INTRODUCTION

A computer simulation of a process can be produced in two ways. One option, termed here as a "specified end use" simulation, is developed by having a programmer take the governing equations for all of the chemical operations that make up the specified process and translate them into a computer program. The programmer then takes physical property data and an equation of state and solves this system of equations either simultaneously in a matrix, or sequentially, usually in the order in which the operations occur. This option produces a computer program that will simulate the process but the program is "end use specific" and cannot be altered easily.

The other option makes use of a process simulator. A process simulator is a program in which governing equations of many chemical operations, physical property data and equations of state are made available to the user in a simple, understandable format. The simulator requires the user to specify only the type of equipment, the connections between equipment, the compounds to be considered in the model and the equation of state that is to be used in the simulation. This allows for more than one process to be simulated, ie. it is not "end use specific", by a user who does not have programming skills. Therefore more people can simulate more processes in less time.

In this work we are using the process simulator ASPEN (Advanced System for Process Engineering) to simulate the CFB Summerside steam heating

plant. ASPEN is a system which contains a physical property databank for many compounds and Fortran code which simulates many chemical processes, equations of state and economic analysis and costing routines.

The work in process simulation with a process simulator such as ASPEN is in the development of a block diagram eg. Figure 5. A block diagram is the translation, using the chemical operation models available in the simulator, of the physical process into a form which can be understood by the simulator. Since a simulator may not contain every physical operation that exists in a process, often more than one simulation block will be required to model one processing step. In other cases some processing steps are unnecessary in the simulation and are not included in the block diagram. Due to these factors the block diagram may not "look" like the process flowsheet, but the operation of the process is mimicked as closely as possible by the block diagram of a simulator.

In this chapter the thermodynamic data used in the simulation will be presented along with the ASPEN block diagrams of the three sections presented in chapter 3. Also discussed will be the Fortran model of the fluidized bed and the interdependent operation of the three ASPEN block diagrams.

It should be noted that only one of the two parallel boiler trains has been modelled. If both boilers are operating identically a simple doubling of the results will predict the total plant output. If the boilers are running under different conditions, two simulations would have to be completed with their results summed.

4.2 THERMODYNAMIC DATA - ACQUISITION AND VALIDATION

To properly model any process, accurate thermodynamic data for each of the chemical species considered in the simulation is required. Also required is a suitable equation of state. This section presents the work done in the acquisition and validation of the thermodynamic data which is used in the simulation.

Due to the nature of the compounds in the simulation and the temperatures and pressures involved in the Gas/Solids Flowsheet it was decided that the Ideal Gas Law (SYSOP0) would be used in this simulation. Bajura (1982) tried other equations of state but the Ideal Gas Law gave identical results and a more robust simulation. In the Steam/Water Flowsheet, the steam table generating routines in ASPEN (SYSOP12) are used. The accuracy of the ASPEN-generated steam tables was verified by Bajura (1982).

Thermodynamic constants for the gases were supplied by the ASPEN databank.

Required constants are:

- molar mass
- freezing point
- boiling point
- critical temperature
- critical pressure
- critical volume
- critical compressibility

- constants for a polynomial heat capacity equation
- standard heat of formation
- Gibbs free energy of formation

This data was checked against data from Reid, (1977) and verified to be correct. The verified thermodynamic data for the gases is shown in Appendix V.

The solids are handled quite differently; since the thermodynamic data for the ash (represented in the simulation by silicon dioxide) and the limestone are not available in ASPEN, they have to be entered separately.

Required data includes:

- molar mass
- standard heat of formation
- Gibbs free energy of formation
- coefficients for a polynomial heat capacity equation
- coefficients for a polynomial molar volume equation

This data, collected from Rossini (1952), Smith (1975) and Weast (1985) is supplied to the simulation in the "PHYSICAL PROPERTIES" section of the ASPEN input file. The verified thermodynamic data for the solids is also shown in Appendix V.

The coal enthalpy and density are calculated internally by ASPEN from the proximate, ultimate and sulfur analysis of the coal. The accuracy of these correlations was verified by Bajura (1982).

4.3 COAL AND LIMESTONE PREPARATION FLOWSHEET

As shown in Figure 5, the ASPEN flowsheet for this system is simple. The coal and limestone feeds are treated similarly; raw feed is separated by a screen with the oversize routed to a crusher. The stream exiting the crusher and the screen undersize are then mixed and the resulting mixture is sent to the boiler.

A difficulty arose when it was realized that the plant data for the coal and limestone particle size distributions is reported on a "as-fired basis". It was impossible to exactly duplicate this feed by mixing the coal crusher outlet and screen undersize streams. To solve this it was decided to sever the contact between this flowsheet and the flowsheet containing the boiler model. The stream "PREFEED" in the Gas/Solids Flowsheet contains the "as-fired" information supplied to us.

4.4 GAS/SOLIDS FLOWSHEET

An ASPEN flowsheet for these systems is shown in Figure 6. The unit operation models that are used include fans, mixers, splitters, reactors, a baghouse and heaters. An ASPEN block name usually specifies its operation, but for clarity the operation of the reactor and heater type blocks, and some of the unique features of ASPEN, are explained below.

FIGURE 5

CFB Summerside - ASPEN Simulation ASPEN Block Diagram for the Coal and Limestone Preparation Flowsheet

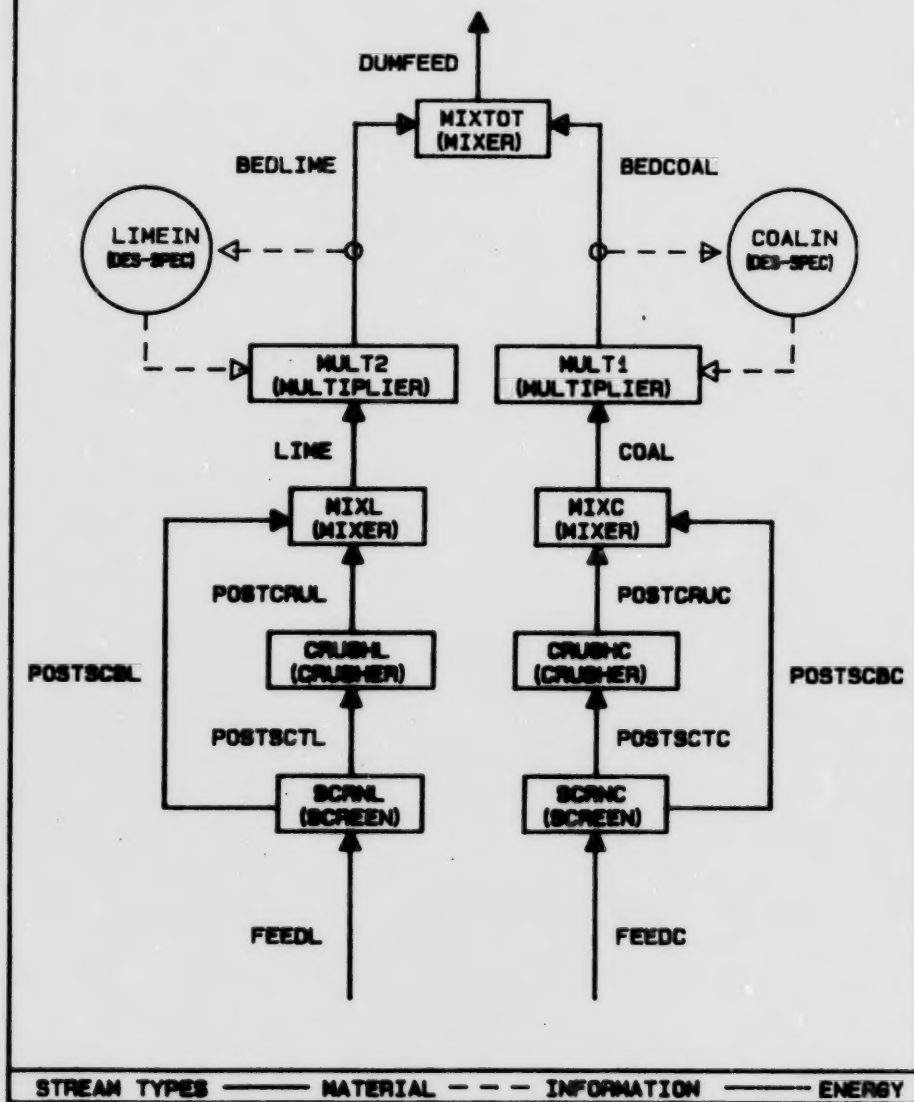
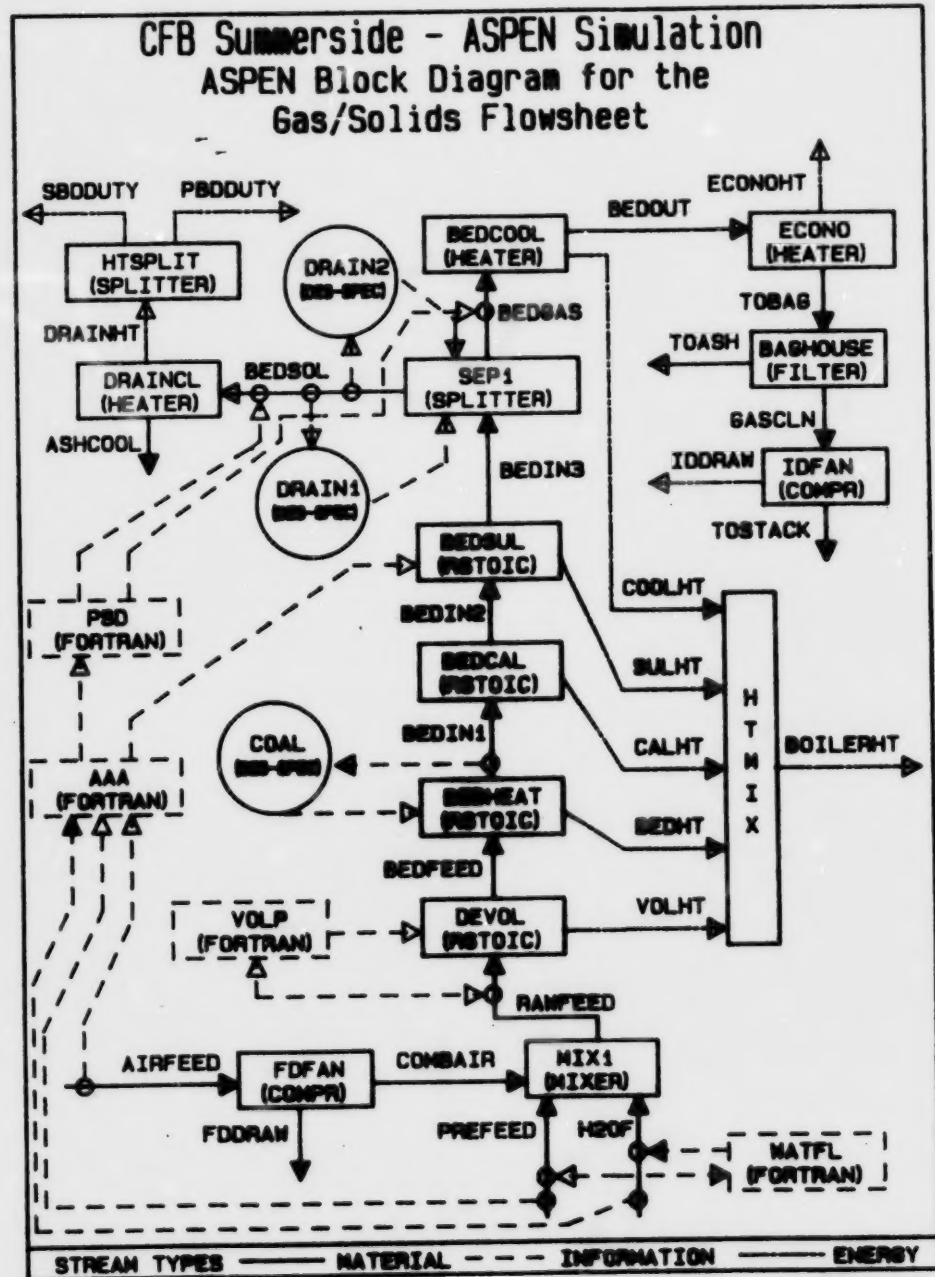


FIGURE 6



The reactors used here take a given reaction stoichiometry, fraction of conversion for the key component, reaction temperature and pressure and compute the composition of the outlet streams and the heat generated or absorbed by the reaction. This model is useful in predicting the heat generated by the coal combustion once the extent of reaction is known.

A heater block computes the change in enthalpy that occurs when a stream changes from its inlet conditions to specified outlet conditions. Heater blocks are not unique to ASPEN but serve many useful purposes. Due to a unique ASPEN feature, the "heat" stream. These "heat" streams transport energy to and from processing blocks. For example, the heat that is removed from the solids withdrawn from the bed in the bed drain coolers is transported in heat streams to the feedwater preparation flowsheet without the need for inefficient heat exchanger models. This allows each flowsheet to be solved separately which produces accurate predictions more rapidly. "Electricity" streams are also available in ASPEN, this facility allows the user to specify an inlet power to a pump or have the program output the required power.

Another feature, the "Design Specification", acts as a controller in the block diagram. Using this feature the modeller can manipulate a variable in the flowsheet (conversion of a key component, mass fraction in a splitter, etc.) to produce a required value in another flowsheet variable. Design specifications are useful when only overall results are known and internal modifications to a flowsheet variable must be made to produce the specified overall results. ASPEN also allows the user to input his own Fortran code to model processes that are not now available in ASPEN

or to use relationships between variables that can be translated into Fortran code to increase the accuracy of a simulation. This ability of ASPEN was often put to use in this work.

The program acts upon the feed streams of coal, limestone and air in the following manner: The first processing step is the pressurization of the incoming air stream "AIRFEED" in the block "FDFAN". Next the Fortran block "WATFL" takes the surface moisture of the coal and puts it in its own stream "H2OF". New "dry-basis" analyses for the coal are then calculated by this block. In block "MIX1" the air, water, coal and limestone streams are mixed. The Fortran block "AAA" is then executed. "AAA" is the fluidized bed model and is discussed at length in section 4.4.1. It is enough to say here that "AAA" defines the operation of the bed by setting the parameters of the reactors and splitters in this section. Blocks "DEVOL", "BEDHEAT", "BEDCAL" and "BEDSUL" perform the following operations on the feed in order: devolatilization of the coal, char combustion, limestone calcination and sulfur capture. Heat duties, positive or negative, are sent through "heat" streams to the mixer "HTMIX". Next, the block "SEP1" separates the remaining solid particles into the bed drain stream "BEDSOL" and the exit gases "BEDGAS". The particle size distributions and the flowrates of the solids in these streams are calculated by block "AAA". "BEDCOOL" simulates the convection boiler bank by cooling the overhead stream to 270°C (520°F). The heat removed here is also transported to the block "HTMIX" which is executed at the end of this flowsheet. "DRAINCL" acts as the bed drain coolers in its cooling of the removed solids to 120°C (250°F). The heat produced here is transported to the splitter block "HTSPLIT". "HTSPLIT" separates

this heat into two equal "heat" streams "SBDDUTY" and "PBDDUTY", one for the preferential bed drain and one for the secondary bed drain. This heat is then transported to the Feedwater Preparation Flowsheet. The heater block "ECONO", which simulates the economizer, then cools the combustor exit gases to 175°C (350°F). The heat removed in "ECONO" is used to pre-heat the boiler feed water stream. The final particulate cleaning system is the block "BAGHOUSE". Finally the gas stream is brought back to atmospheric pressure in the block "IDFAN".

4.4.1 FLUIDIZED BED MODEL

In ASPEN, no module to simulate a fluidized bed is available. The ASPEN simulator does however allow users to input their own models, written in Fortran, into the simulation. This is the approach used here. Fortran code, nested within the ASPEN input file, controls the operation of six ASPEN blocks which, taken together, simulate the fluidized bed. The development and operation of the Fortran code used to model the fluidized bed is presented in this section.

Many fluidized bed models, of varying complexity and accuracy, are available in the literature. These models range from a simple chart which estimates design and performance parameters, Ganapathy (1981), to detailed studies that include such phenomena as gas concentration, reaction kinetics, carbon concentration, heat transfer and temperature profiles,

Gordon (1976). To decide among these it is necessary to define the quantities that must be predicted by the model and to determine a prospective model's applicability to the system under study. The quantities deemed necessary for this study are:

- Accurate calculation of combustion heat release.
- Accurate modelling of solids size distributions and elutriation rates.
- Accurate prediction of sulfur capture efficiency.
- Reasonable solution time.

These requirements eliminated those models which included predictors of gas phase behavior or temperature profiles of the bed and freeboard since these models are both time consuming and provided more information than was required. No heat transfer models were examined since it was assumed that the bed had enough heat transfer surface to collect all the recoverable heat generated by the coal combustion.

The "FLUIDIZATION ENGINEERING" textbook by Kunni and Levenspiel was used by many authors, Ray (1978 & 1980), Congalidis (1981), Charagundla (1977), Donsi (1981) and Chen (1977) as the basis for calculating their solids population balance. The textbook also provided methods for handling particle size reduction, segregation within the bed due to overbed or underbed feeding and recycle of dust captured by cyclones. Since this textbook provided a simple means of calculating the requirements stipulated above it was decided to use this source for the model in the simulation.

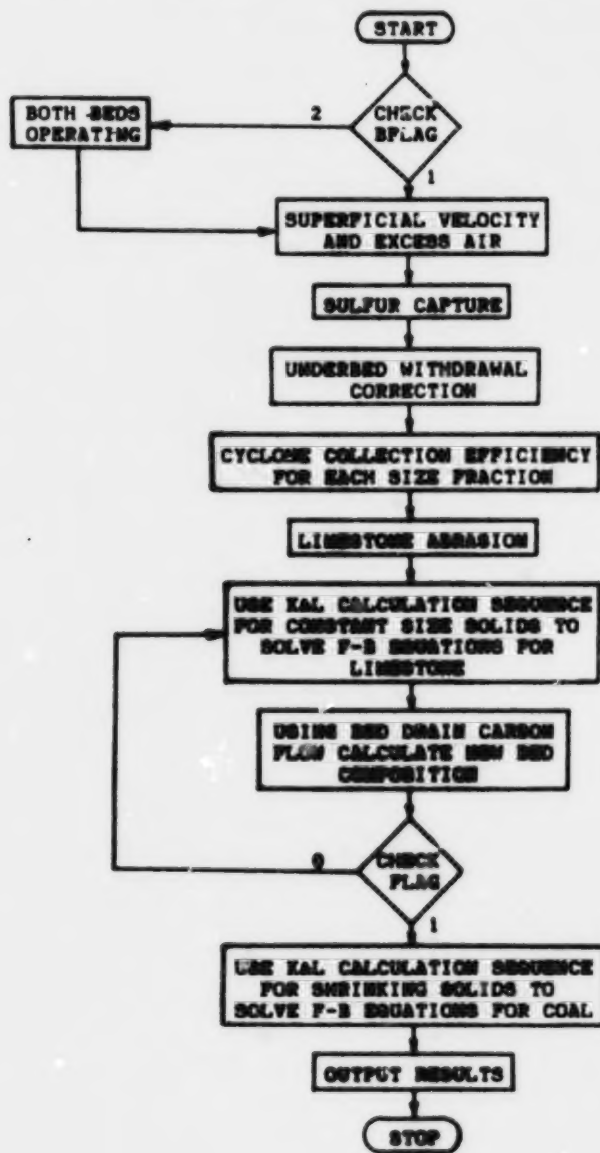
Since sulfur capture is a function of the reactivity of the limestone none of the models in the literature can be expected to model every case. It was decided here to regress plant data to get a simple model of the sulfur capture efficiency of the plant. The textbook model was translated into Fortran code along with the linear sulfur capture model. A discussion of the final model follows.

The Fortran code used here to simulate the fluidized bed is the model presented by Kunii and Levenspiel in their textbook "FLUIDIZATION ENGINEERING". Peripheral programming steps have been added around this model to speed up the calculation sequence and allow the computation of other required values.

An algorithm of the program is shown in Figure 7. After initiation and collection of required data from ASPEN streams, the program checks to see if one or both beds are operating. If only one bed is operating, a smaller bed surface area and mass of bed are used. Next, the excess air that has been supplied to the combustor and the superficial velocity of the combustion gases are calculated. The sulfur capture efficiency is then calculated from a linear correlation generated from plant data.

The Fortran code contains, along with the solids population balance equations, the following three peripheral calculations which are required to accurately model the plant. First, the textbook model was developed assuming that an overflow weir would be used to withdraw solids from the bed. At Summerside they use a drain pipe at the bottom of the bed. This forced us to use a underbed withdrawal correction that was described in

FIGURE 7 : Schematic for Portran Fluidized Bed Model



Kunii and Levenspiel (page 332). The magnitude of the correction factor depends on the degree of segregation in the bed. Factors for each size fraction considered in the model were calculated using plant data. Second, the cyclone collection efficiency for each size fraction is required by the model. The correlation used here is from ASPEN and uses the density of the particles and a mean particle size captured to characterize the system. The particle densities are from ASPEN and the mean particle diameter collected was calculated using an error minimization technique which is discussed later in this section. Third, from the size differences between the inlet and outlet solid streams, the limestone particles do not remain constant in size as they reside in the bed. Here it is assumed that the process acting on these particles is abrasion. This phenomena has been modelled by assuming that the abrasion of non-elutriable size fractions will produce a decrease of mass in this fraction with a corresponding increase in elutriable size fractions. This process keeps the total mass supplied to the bed constant. The amount of abrasion that is undergone by each non-elutriable size fraction was determined using the error minimization technique mentioned outlined below.

The fluidized bed equations for constant size particles taken from Kunii and Levenspiel are then solved using the new limestone size fractions. Using the calculated limestone withdrawal rate and a coal withdrawal rate calculated from a correlation found in Anthony, et al., (1985), the masses of coal and limestone in the bed, assuming constant total mass, are found. A flag is then checked to see if these new values were used in the fluidized bed equations for the limestone. If they weren't the program returns to the limestone calculations. If they were, the program goes

on to solve the fluidized bed equations for the shrinking coal particles. Once this is completed, the results are used to control several ASPEN blocks in the simulation.

To tailor the model to the CFB Summerside combustor the effective coal combustion rate (includes both combustion and mechanical size reduction), the limestone abrasion rate and the average particle diameter collected by the multiclone were set using error minimization on the best set of plant data available. The best set of plant data is the 24 hour combustion trial with Devco coal at 100% load. Using this data the three parameters were varied until the lowest total error (calculated by summing the percent errors in the mass flow, average particle diameter and mass fraction carbon in the overhead and underflow streams) was found. The resultant values for these parameters were kept constant for the rest of the model runs.

The information generated by this block of FORTRAN programming defines the flowrate, composition and particle size distributions of the solids leaving the combustor, the combustion efficiency of the coal and the sulphur capture efficiency of the process.

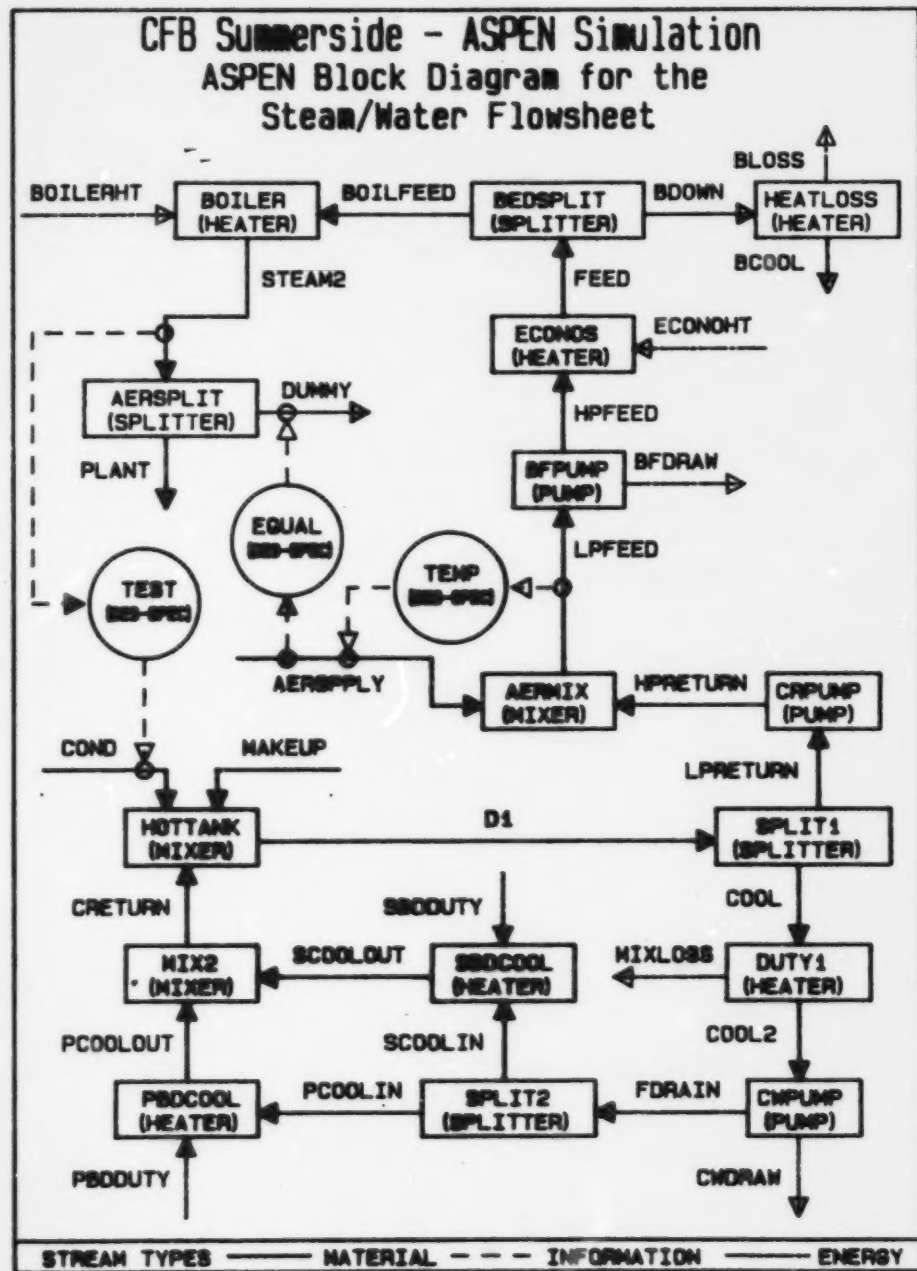
4.5 STEAM/WATER FLOWSHEET

An ASPEN flowsheet for the Steam/Water flowsheet is shown in Figure 8. The mixer "HOTTANK" brings together the condensate, makeup water and the water returning from the bed drain coolers. The total flow of these stream is then split into two streams, one to supply the bed drain coolers, the other to feed the boiler.

The bed drain feed stream, "COOL" is cooled to simulate the heat loss in the "HOTTANK", then pumped up to 274 kPa (40 psia) in block "CWPUMP", and subsequently split in "SPLIT2" before it enters the drain cooler blocks "SBDCOOL" and "PBDCOOL". The two exit stream are then joined in "MIX2" and fed back into the "HOTTANK".

The boiler feed stream "LPRETURN" is pumped up to 136 kPa (20 psia) by block "CRPUMP" before it enters the de-aerator block "AERMIX". In the de-aerator the boiler feed stream is mixed with an appropriate amount of steam such that the exit temperature of the de-aerator is 104°C (220°F). This stream is then passed to a compressor, block "BFPUMP", where its pressure rises to 1 480 kPa (215 psia). This high pressure feed water is then transferred to block "ECONOS" where it is acted on by a heat stream that was generated in the Gas/Solids Flowsheet block "ECONO". This high temperature water is then split by block "BEDSPLIT", with 91 kg/hr (200 lb/hr) going to stream "BDOWN" and the rest being acted on by the remaining heat produced by the coal combustion in block "BOILER". This blowdown stream is then cooled to 27°C (80°F) in block "HEATLOSS" to

FIGURE 8



provide a quantitative measure of the heat lost in this stream. The steam produced in the boiler is then split in block "AERSPLIT" with a portion, equal to the steam flowrate entering the de-aerator, removed from the total flow of steam produced by the boiler. The remaining steam leaves the boilerhouse to supply the base.

4.6 FLOWSHEET CONVERGENCE AND CONTROL

The combined flowsheets have eight design specifications and only one recycle loop. This lack of recycle loops allows the program to finish in just over four CPU seconds.

The two design specifications that control the solids preparation system limit the flow of solids from this flowsheet to the next. This is necessary since the solids preparation flowsheet handles 22.7 tonnes/hr (25 tons/hr) of coal or limestone while the boiler only consumes a small part of that. This excess capacity is required at the plant because trucks dump large loads at separate times. ASPEN can only handle continuous flows, therefore multiplier blocks, which simply multiply the flow rate of a stream by a pre-set factor, are required to reduce this large flow to the flow required at the boiler. The multiplication factors of these blocks are set by these design specifications.

The three design specifications in the boiler and associated facilities system serve to set the flow of solids out of the combustor to the values that were specified by the Fortran model "AAA". Flowrates controlled are the bed drain coal flow, the bed drain ash flow and the total amount of char leaving the fluidized bed.

The three design specifications in the boiler feedwater preparation system are by far the most interesting. The first of these specifications is named "TEMP" and is used to vary the flow of steam to the de-aerator to keep the outlet temperature at 104°C (220°F). The second named "TEST", controls the flow of steam to the plant. This is done by varying the flow of condensate to the "hotwell" until all the heat provided by the boiler is used to produce steam of the required temperature and pressure. The last named "EQUAL" ensures that an amount of steam equal to that entering the de-aerator is split off the total steam produced by the boiler. This in effect closes a recycle loop, but does so at a greatly increased computational efficiency.

4.7 SUMMARY

The preceding chapter presented an overview of the simulation operates and the level of difficulty involved in this simulation.

Important features to note are:

- The solids preparation flowsheet is not connected to the rest of the simulation.
- The steam flow is allowed to vary directly with the operating conditions of the boiler.
- The simulation includes predictors for the combustion of the coal, sulfur dioxide capture, electricity consumption, production of particulate wastes and total steam production.

The simulation model the CFB Summerside Project is contained in an ASPEN input file that is 924 lines long (see Appendix I). This file is made up of 39 ASPEN unit operation models, 4 user developed Fortran programs totalling 420 lines of code and 8 design specifications that allow the simulation to mimic the plants response to input changes.

5.0 MODEL VALIDATION

5.1 Introduction

5.2 Heat and Material Balance

5.3 Equipment Sizing

5.4 Summary

5.1 INTRODUCTION

To examine the capabilities and limitations of the model described above, information from two sources is used. Checks on the overall heat and material balances of the plant, as well as the particle size distributions of the product solids streams, the production of pollutants and a qualitative examination of the electricity consumption of the plant are all made against actual plant operating data. Equipment sizing data was checked against the information supplied in the Foster-Wheeler design manuals. Results of these checks are provided in tabular and graphical format in this chapter.

5.2 HEAT AND MATERIAL BALANCE

In the Coal and Limestone Preparation Flowsheet, the process of interest is the reduction of the coal and limestone from their respective "delivered" to "as-fired" Particle Size Distributions (PSD). Since the data from the plant only provides "as-fired" PSD's no comparison of our model for the crushing of the limestone and coal against the actual operation at the plant can be made. However, the information provided in the Foster-Wheeler design manuals has been plotted against the values predicted by the model. These results are shown in Figures 9 and 10.

WT FRACTION VS PARTICLE SIZE DISTRIBUTION
 COAL CRUSHING CIRCUIT

FIGURE 9

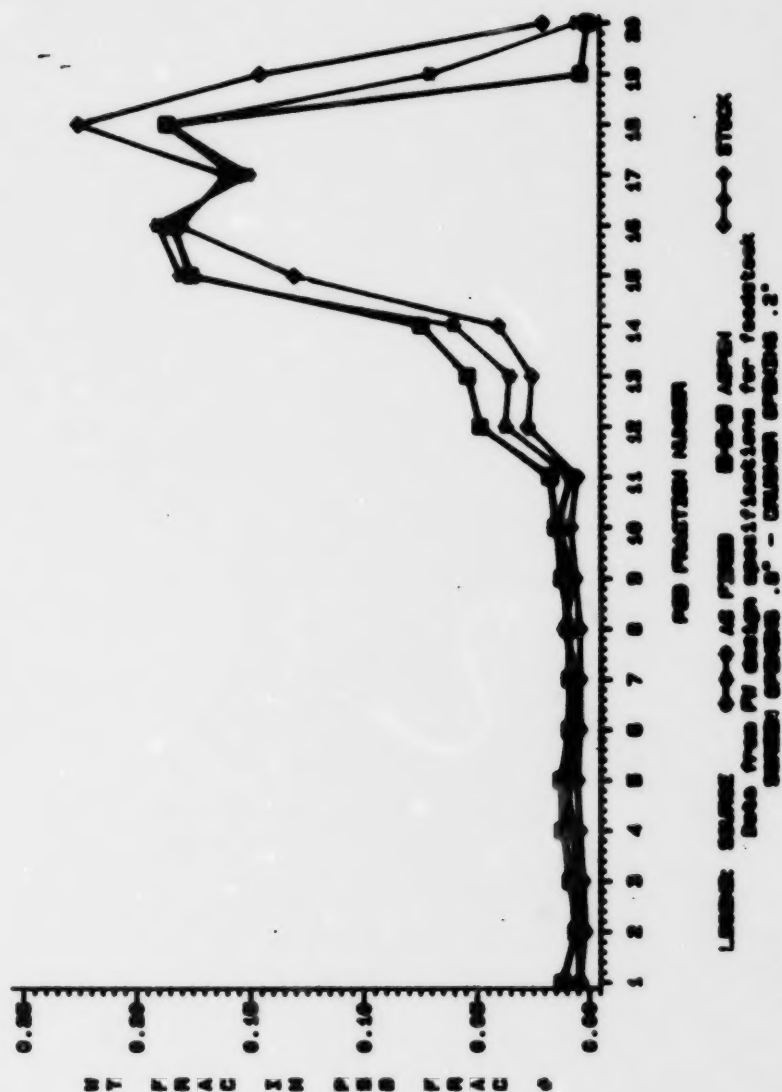
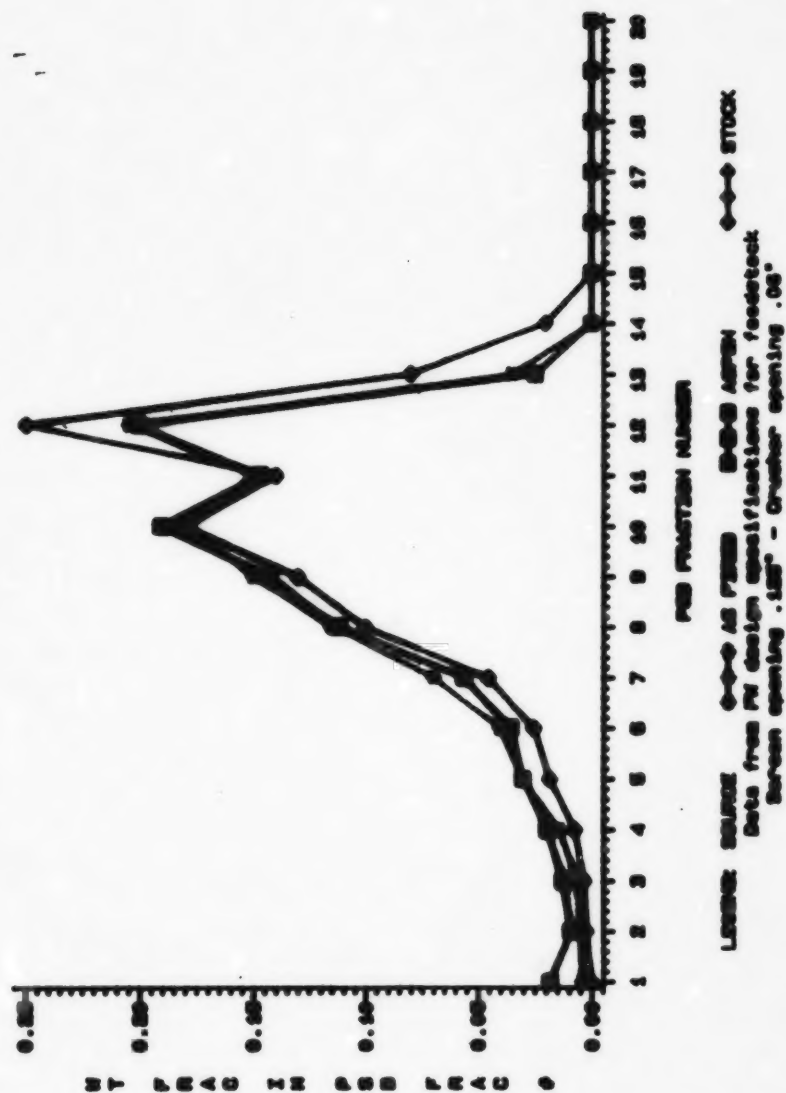


FIGURE 10
WT FRACTION VS PARTICLE SIZE DISTRIBUTION
LABORATORY CRUSHERS COMPARISON



The model does predict the design data well and should predict the actual operating data with close to the same accuracy.

It would be optimal if complete heat and material balances from all six 24 hour combustion trials were available. Unfortunately, only the 100% load Devco coal run is completely specified. The rest of the runs give only particle size analysis, feed flowrates and total steam flow. Also, not all of the trials were used because of the extremely variable coal feed rates recorded. Of the six 24 hour combustion trials, only four had coal feed rate plots on which a likely feed rate could be determined. These runs were used for comparison purposes. The other two runs were eliminated from further consideration. Due to this variability, it was impossible to know exactly what value to use as the feed rate of coal. Fortunately, the model produced good results using an approximate feed rate. A tabular and graphical comparison of the model vs. the plant data follows.

Table 1 presents a comparison between the plant, running at 100 percent load (approximately 18 000 kg/hr (40000 lb/hr)) using Devco coal and Havelock limestone, against the model at the same conditions. All of the significant errors seen in Table 1 can be attributed to the fact that the model predicts a higher carbon burnout. It is possible to make the model predict this run better, but this sacrifices the model's predictive capabilities against other runs.

TABLE 1 : Calculated Values vs. Plant Data

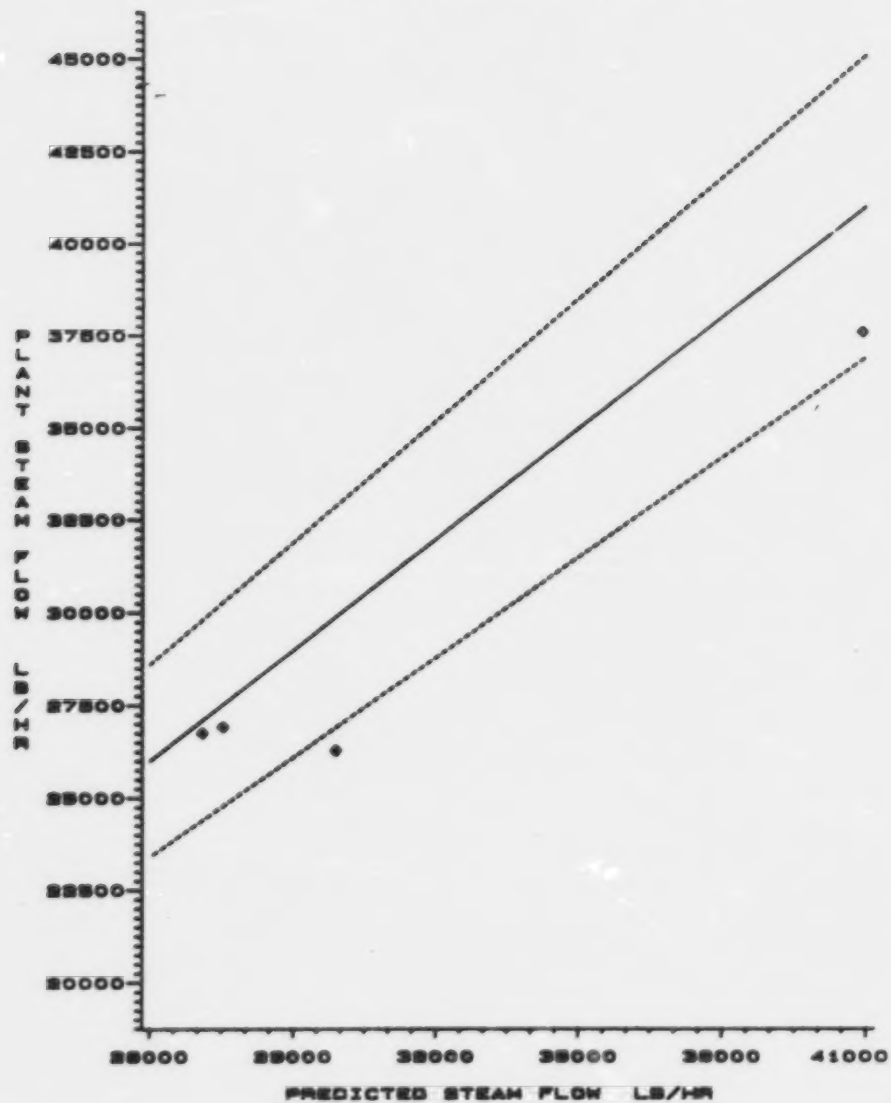
	PLANT	MODEL	% DIFF.
% SULFUR DIOXIDE CAPTURE	84.56	84.44	-0.14
BAGHOUSE - FLOW (kg/hr)	454.2	549.1	+1.53
% CARBON	7.24	6.55	-9.53
BED DRAIN - FLOW (kg/hr)	304.0	301.6	-0.76
% CARBON	0.18	0.122	32.22
STEAM FLOW (kg/hr)	17089	18645	+9.10
% ELEC CONSUMPTION FANS	85--90	88.7	
DRY GAS ANALYSIS (Mass %)			
CO2	15.25	18.30	+20.00
O2	8.53	7.35	-13.83
N2	76.08	74.24	-2.42
SO2	0.0966	0.1062	+9.94

Figure 11 plots the plant steam flow vs. the predicted steam flow with the model running at the same conditions. The solid reference line on the graph depicts perfect agreement. The dashed lines represent 10% deviation from the reference line. Going from left to right on the graph, the points represent the following plant operating loads and coal types; Evans coal 65% load (approximately 13 200 kg/hr (29000 lb/hr)), Devco coal 65% load, Brogan coal 65% load and Devco Coal 100% load. The only run that deviates more than 10% was the Brogan coal at 65% load. It is probable that this deviation is due to measurement error at the plant since the coals are of approximately the same quality and the Brogan coal was fed at a higher rate than both the Devco and Evans coals (at 65% load). Also, these runs have nearly the same feed rates of air and limestone, therefore this run should not produce the lower plant steam output reported in the plant data. The simulation predicts a higher steam flow, which seems to be more reasonable.

It should be noted that the calculated values of the plant steam flow are always higher than that actually produced at the plant. This cannot be avoided since the model is highly idealized with no heat losses from the boiler to the surroundings.

As a final note, the government specified the following limits on sulfur dioxide and particulate emissions, 2.96 kg/10⁶ kcal. and 0.36 kg/10⁶ kcal. respectively (Friedrich, 1982). The model predicts the following sulfur dioxide and particulate emissions, 2.47 kg/10⁶ kcal. and 0.152 kg/10⁶ kcal. respectively. This agreement suggests that the model predicts the plant operation closely.

FIGURE 11
MODEL VALIDATION
 PLANT VS PREDICTED STEAM FLOW DATA

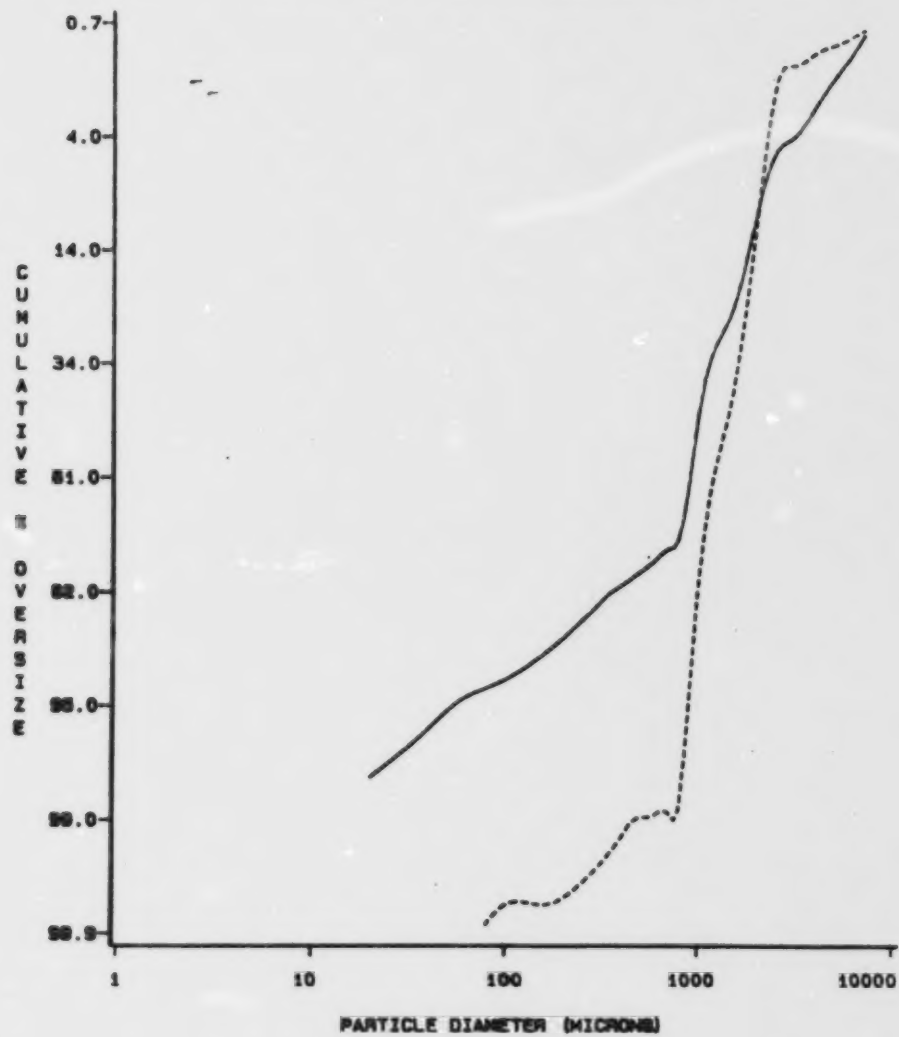


NOTE: DASHED LINES - 10% DEVIATION FROM PLANT DATA

Figures 12 through 19 are the predicted and actual particle size distributions (PSD) of the baghouse ash and the bed drain streams. There is a large gap between the predicted and actual PSD of the bed drain stream at small particle diameters. This is caused by two factors. First, the vertical scale of these plots magnify errors at small diameters and second, the model assumes that abrasion is the only size reducing mechanism that acts on the limestone to produce elutriable particles. This assumption does not produce particles in the size range 100 to 700 microns. Particles in this range must be produced by fracture of large limestone pieces, a mechanism not considered here. If a simple fracture model becomes available its inclusion would increase the accuracy of the model in the 100 to 700 micron particle size range.

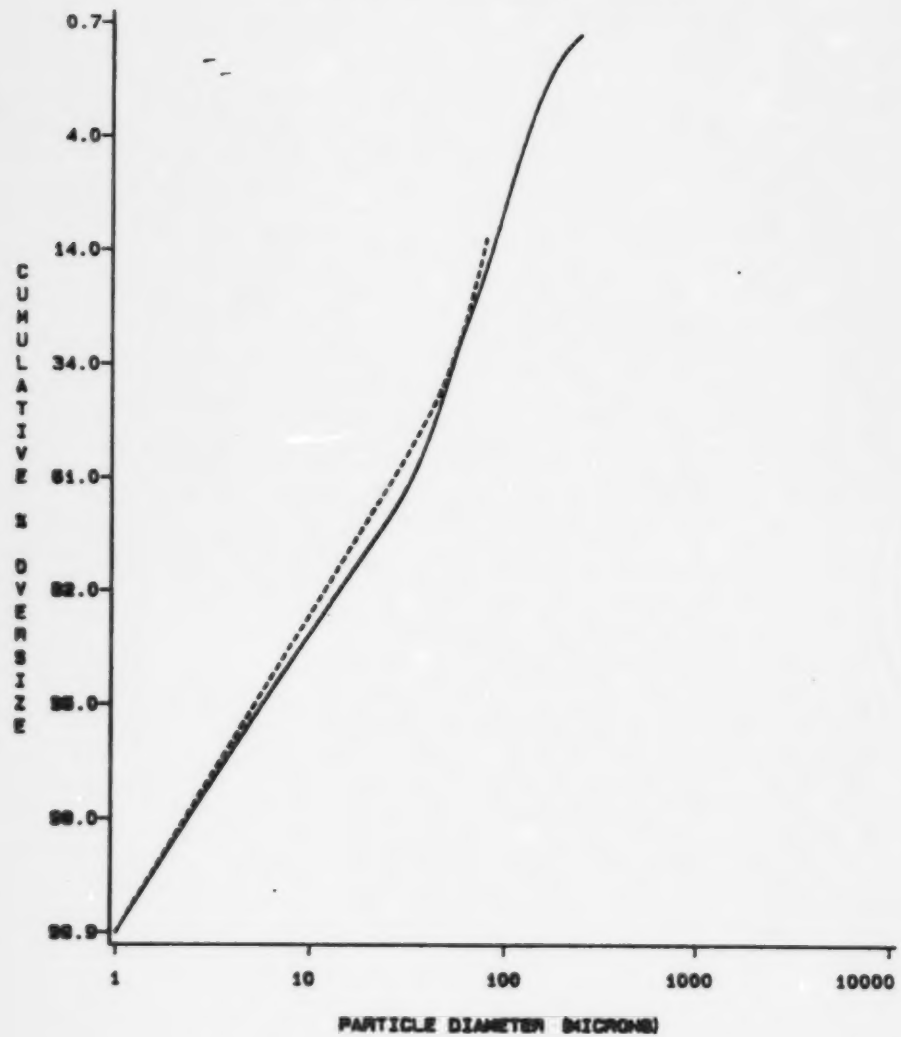
In Figure 19 the model does not predict the baghouse product PSD well. It is not known why the run with Evans Coal at 65% load produces a particle size distribution so unlike the others, but three possibilities can be put forward. First, no solids were produced below 40 microns in diameter, second, the collection efficiency of the baghouse for sub-40 micron particles was small for this one run and third, measurement error in the analysis of the baghouse ash stream was high. It is probable that reason one is not the culprit. Reasons two and three are equally as likely to have happened but they cannot be modelled.

FIGURE 12
CFB SUMMERSIDE - DEVCO COAL 100% LOAD
BED DRAIN PARTICLE SIZE DISTRIBUTION



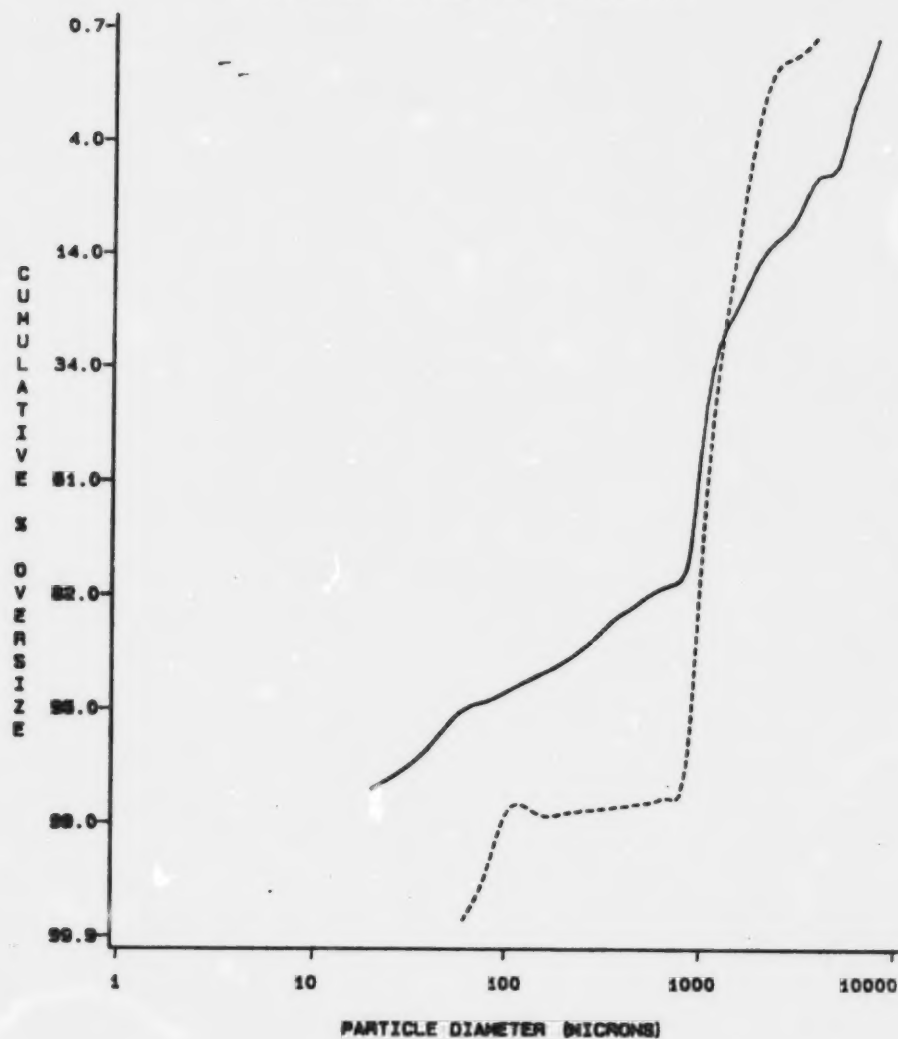
SOLID LINE = PLANT DATA, BROKEN LINE = MODEL

FIGURE 13
CFB SUMMERSIDE - DEVCO COAL 100% LOAD
BAGHOUSE ASH PARTICLE SIZE DISTRIBUTION



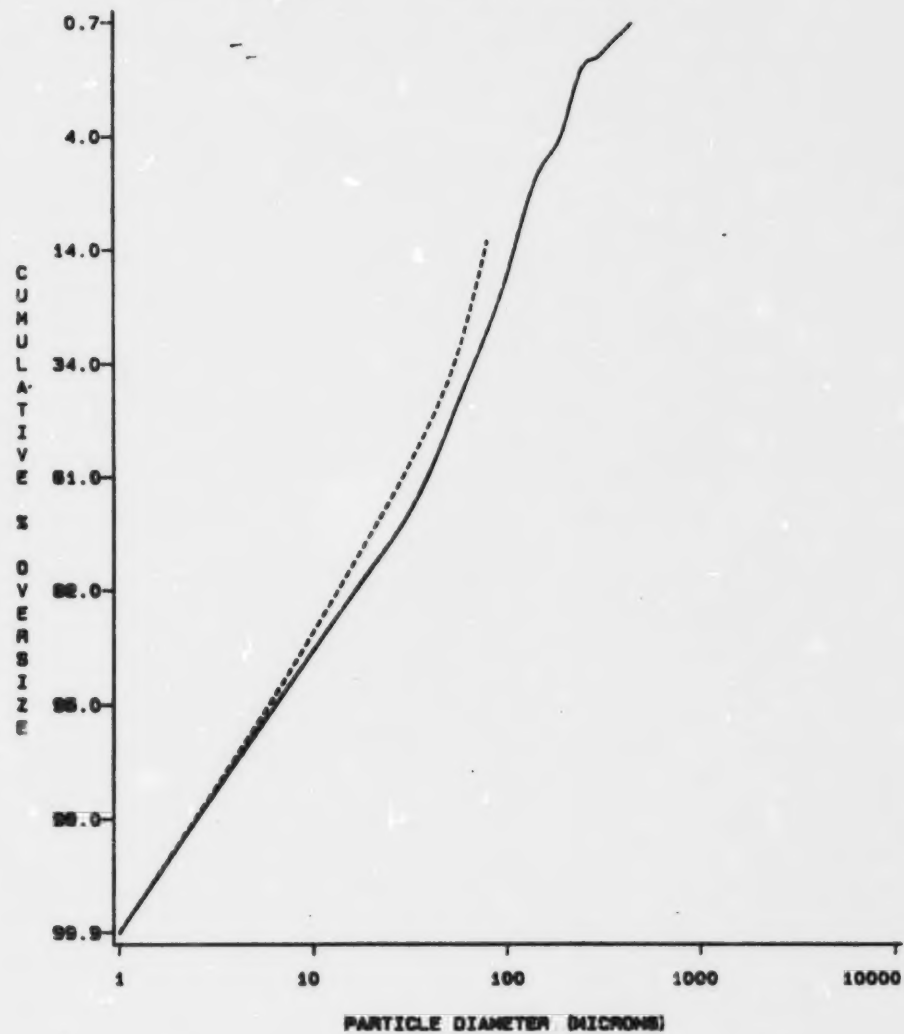
SOLID LINE - PLANT DATA, DASHED LINE - MODEL

FIGURE 14
CFB SUMMERSIDE — DEVCO COAL 65% LOAD
BED DRAIN PARTICLE SIZE DISTRIBUTION



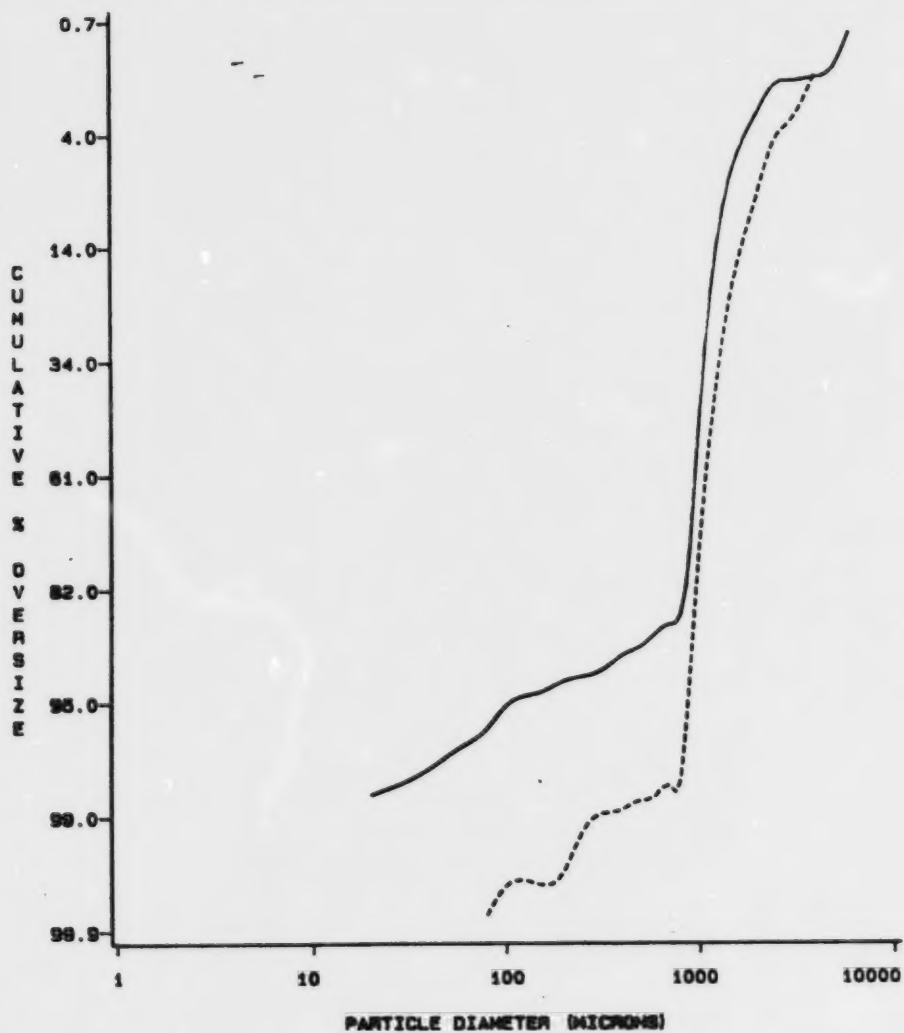
SOLID LINE — PLANT DATA, BROKEN LINE — MODEL

FIGURE 15
CFB SUMMERSIDE — DEVCO COAL 65% LOAD
 BAGHOUSE ASH PARTICLE SIZE DISTRIBUTION



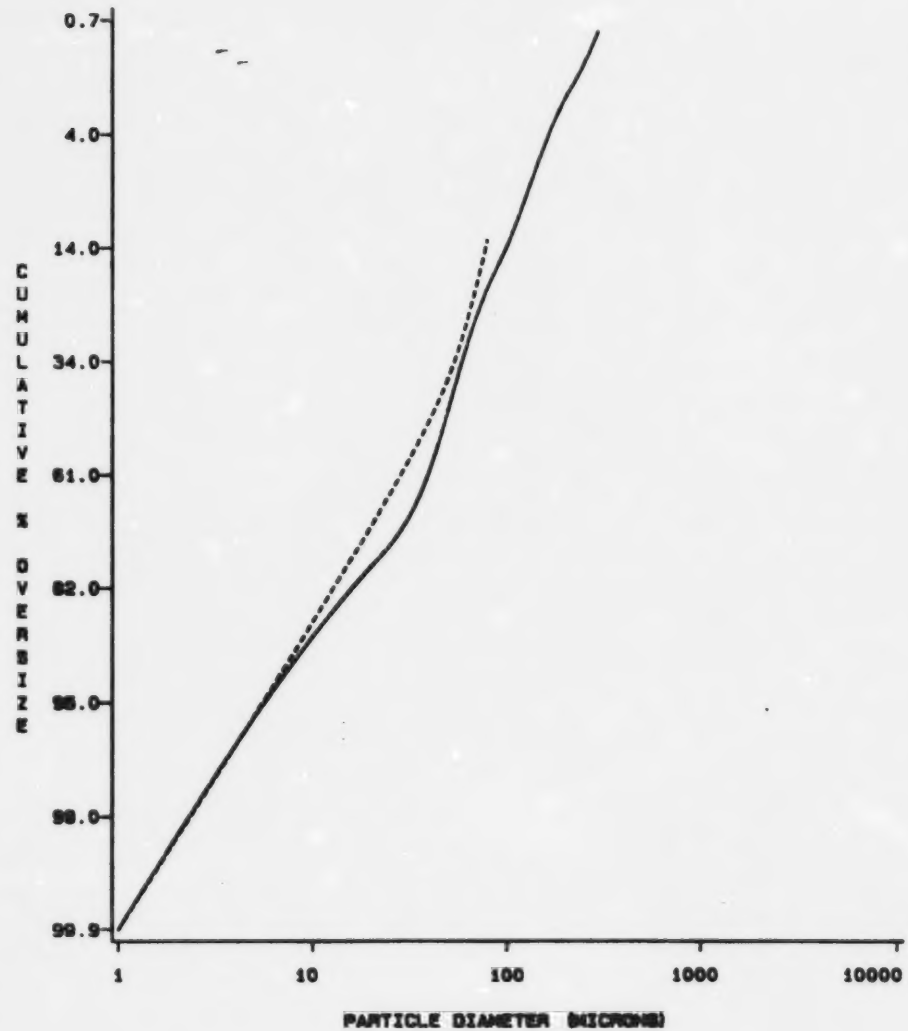
SOLID LINE — PLANT DATA, BROKEN LINE — MODEL

FIGURE 16
CFB SUMMERSIDE - BROGAN COAL 65% LOAD
BED DRAIN PARTICLE SIZE DISTRIBUTION



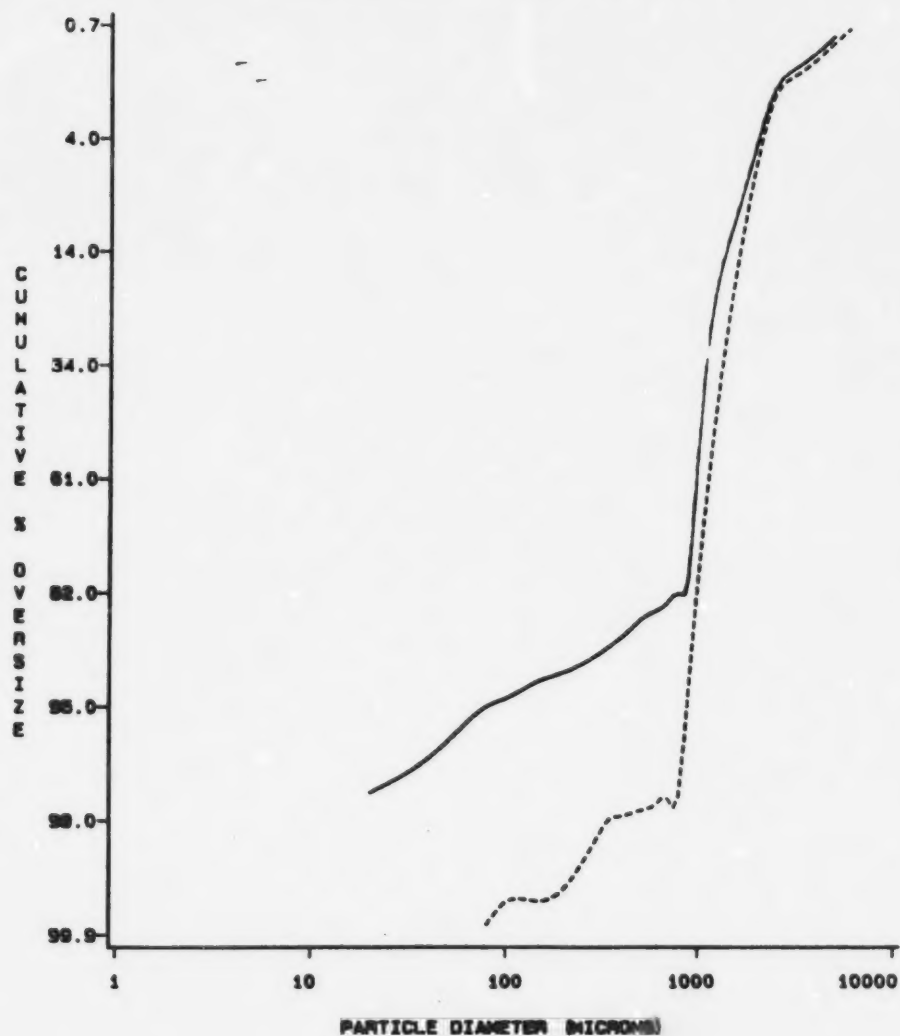
SOLID LINE - PLANT DATA, BROKEN LINE - MODEL

FIGURE 17
CFB SUMMERSIDE - BROGAN COAL 65% LOAD
BAGHOUSE ASH PARTICLE SIZE DISTRIBUTION



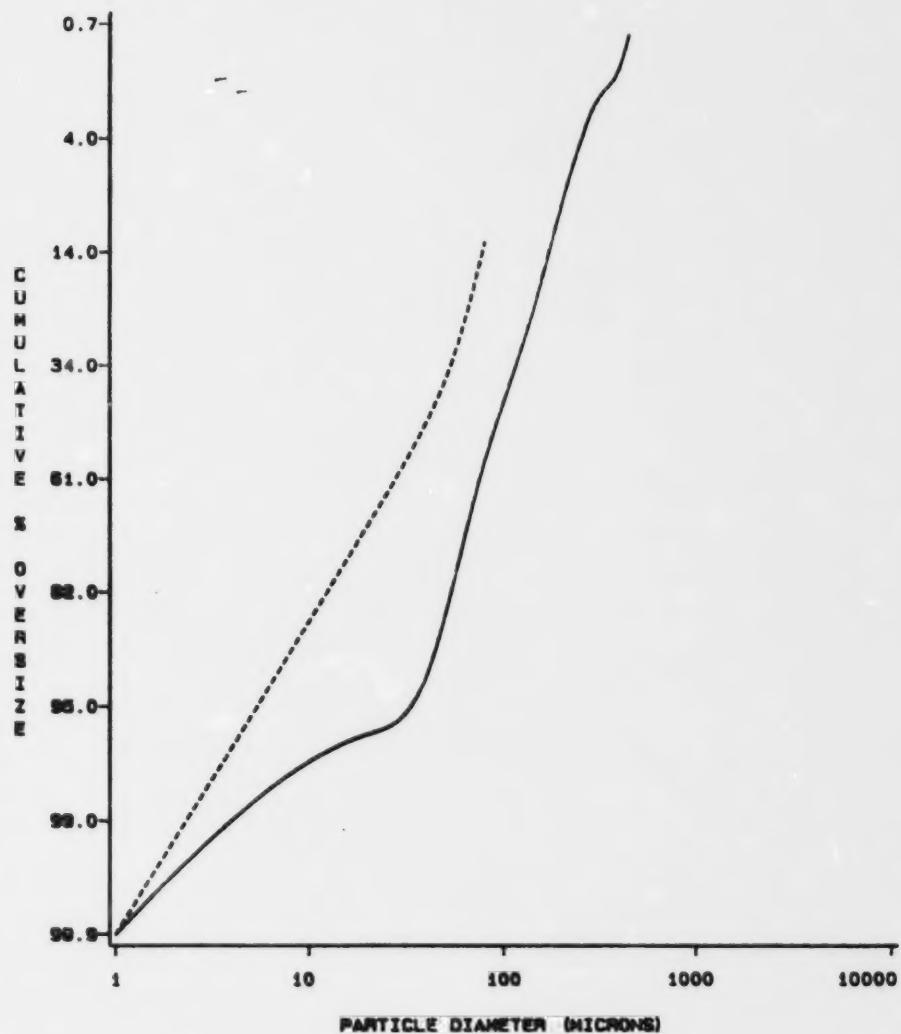
SOLID LINE - PLANT DATA, DASHED LINE - MODEL

FIGURE 18
CFB SUMMERSIDE - EVANS COAL 65% LOAD
BED DRAIN PARTICLE SIZE DISTRIBUTION



SOLID LINE - PLANT DATA, DASHED LINE - MODEL

FIGURE 19
CFB SUMMERSIDE — EVANS COAL 65% LOAD
BAGHOUSE ASH PARTICLE SIZE DISTRIBUTION



SOLID LINE = PLANT DATA, BROKEN LINE = MODEL

5.3 EQUIPMENT SIZING

Table 2 compares necessary equipment sizes calculated by ASPEN vs. the equipment specified by Foster-Wheeler.

TABLE 2 : Equipment Sizing Results vs. Plant Data

	PLANT	MODEL	% DIFF.
Forced Draft Fan (hp)	300	205	-31.67
Induced Draft Fan (hp)	125	51	-59.20
Cooling Water Pump (hp)	3	3	0.00
Condensate Return Pump (hp)	3	.75	-75.00
Boiler Feed Pump (hp)	40	30	-25.00

It is obvious ASPEN does not agree well with the engineers at Foster-Wheeler. Closer agreement may have been possible if it was known at what load and with what percent overdesign the engineers used as a basis for their calculations. Here Devco coal at 100% load and 50% overdesign was used. It is likely that they were using 110% load and about the same overdesign. Even with a higher overdesign there would still be a discrepancy in the motor size of the Condensate Return Pump. Foster-Wheeler specified the same motor for the Cooling Water and Condensate Return pumps which have about the same flowrate, but the Cooling Water pump's required pressure rise is 5 times that of the other. Possibly Foster-Wheeler was trying to economize by using a standard motor for both these pumps.

5.4 SUMMARY

In this chapter the model's predictive capabilities have been examined with the following results:

- The overall heat and material balances match closely.
- The PSD and composition of the baghouse ash and the solids withdrawn from the bed are modelled well.
- Equipment sizes predicted by ASPEN were below or equal to those chosen by the Foster-wheeler engineers.

- 75% of the available plant data for steam flow was predicted to within 10% by the model.
- The fraction of the overall power draw of the forced draft and induced draft fans is within limits outlined to us (Razbin (1986)).
- The predicted pollutant production is close to the values specified by the government in their contract to Foster-Wheeler.

Closer agreement between the PSD's of the plant and the model may be possible with the inclusion of a model for the fracture of the larger limestone particles which enter the bed, rather than the simple abrasion model used here.

As a whole, the model behaved well with accurate results being produced. The model also proved itself to be robust since it provided converged results rapidly irrespective of inlet or reactor conditions.

6.0 ECONOMIC ANALYSIS

- 6.1 Introduction
- 6.2 Costing Data - Acquisition and Validation
- 6.3 Fixed Capital
- 6.4 Operating Expenses
- 6.5 Summary

6.1 INTRODUCTION

The economic analysis of a project includes the following:

- Capital costs for the project and any alternatives.
- Operating costs for the project and any alternatives.

Procedures to obtain this information, given process flowsheets and heat and material balances for the subject process and any alternatives, are available in the literature. A description of one of these procedures, used here in the economic comparison of fluidized bed steam raising vs. electricity in district heating, is presented in this chapter.

6.2 COSTING DATA - ACQUISITION AND VALIDATION

Economic analysis techniques presented in the literature require the following data:

- A complete "Heat and Material Balance"
- A list of "Main Plant Items" (All items larger than the smallest pump.)
- Delivered costs for the "Main Plant Items"
- Operating expenses

The heat and material balances are provided by the simulation but the decision as to what to include in the "Main Plant Items" has to be made. Fortunately, the Foster-Wheeler manuals provide a complete listing of the "Balance of Plant" equipment. The elimination of the smaller items on this list provided us with a good idea of the required "Main Plant Items". Eliminated items include:

- Water softening system
- Light oil pumps
- Light oil duplex strainer
- Light oil tank
- Chemical mix tanks
- Chemical proportioning pumps
- Air conditioner
- Roof exhaust fans
- Air dryer

Items included in the "Main Plant Items" are:

- Electric boiler feed pump
- Cooling water pumps
- Condensate return pumps
- Emergency diesel generator
- De-aerator
- Air compressors
- Bucket elevators
- Screw conveyors

- Screw feeders
- Vibrating feeders
- Scraper conveyor
- Belt conveyor
- Coal crusher
- Vibrating screen
- Vibrating bin dischargers
- Tramp iron magnet
- Ash handling systems
- Baghouse

The two lists above do not include, for reasons outlined below, all the data that was provided in the "Balance of Plant" list. Large plant items that have been ignored include:

- Limestone handling system screen
- Limestone crusher
- Wood handling system screen
- Wood chipper

Since the plant purchases double-screened limestone from its supplier, the requirement for limestone processing at the plant is eliminated, so the limestone screen and crusher are obsolete. A plant built today would not include these items and therefore they were not included in the economic model. The provision for wood chip feed to the boiler was for demonstration purposes only. Any commercial plant would not include

costly equipment to supply a low quality feed with an uncertain supply cost and availability to the boiler.

Noticeably absent from the list above are the boiler, blowdown tank, economizer and the forced and induced draft fans. Costs for these items were provided by personnel from Foster-Wheeler as a packaged unit and are included in the final cost summary under the heading, BOILER.

Once it had been decided which pieces of equipment were to be considered as "Main Plant Items", delivered costs had to be determined for them. It was decided that the costing equations in ASPEN would be used wherever possible, with the rest of the costs coming from literature sources. The ASPEN cost correlations were validated by the developers of ASPEN at the time of their inclusion into the ASPEN code. They have also been validated by other workers here at Queen's University, Ham (1986).

To eliminate some of the error that is associated with literature cost correlations it was decided that where possible, a composite correlation made up of data from more than one source would be used. Examples of this work are shown in Figures 20 to 24. A listing of the final correlations used and the references where they came from is shown in Table 3.

The input file for the costing of the pumps, de-aerator, and the baghouse is shown in Appendix II. This file contains all the information that is used by ASPEN to calculate the total fixed capital required to build a plant to house the equipment costed by ASPEN. Only the information used to calculate the costs of the specified equipment is pertinent here.

FIGURE 20
9 Inch Screw Conveyor Costs
1979 Dollars

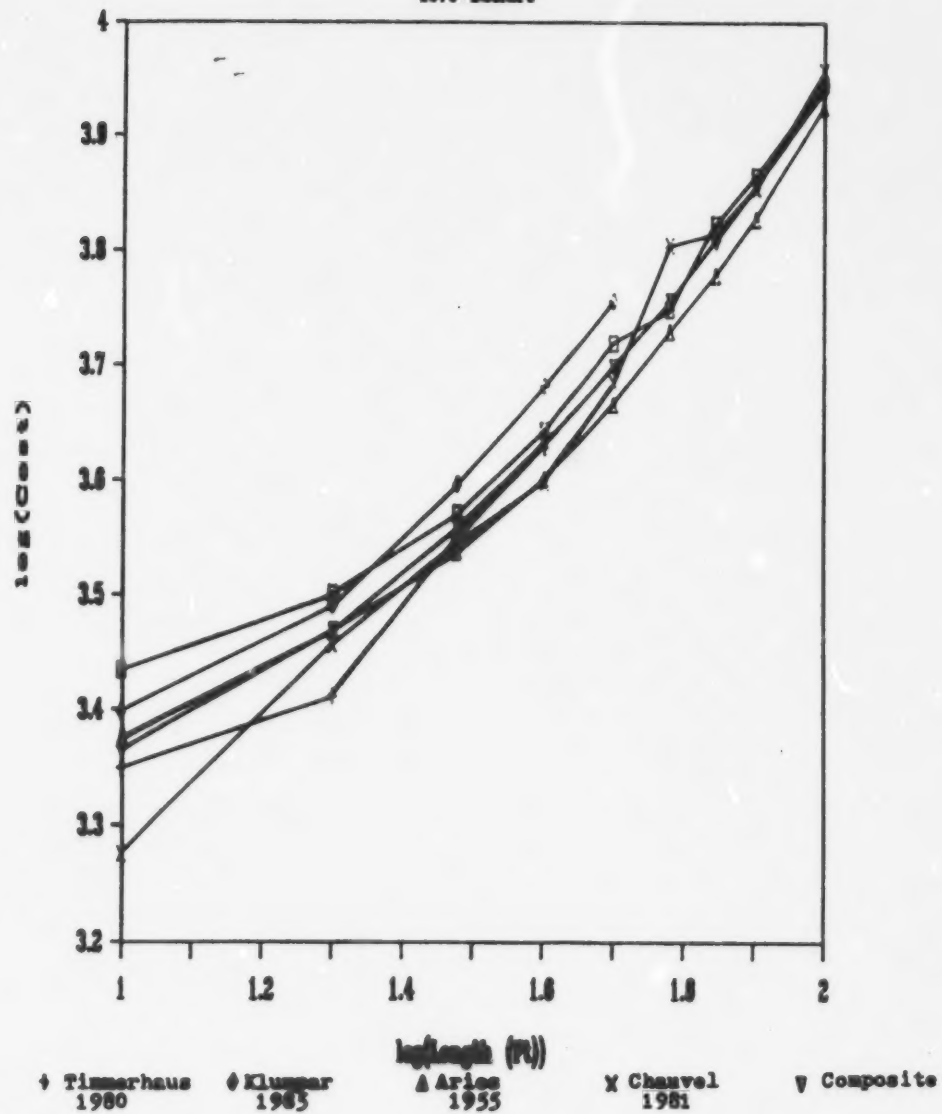


FIGURE 21
14 Inch Screw Conveyor Costs
1979 Dollars

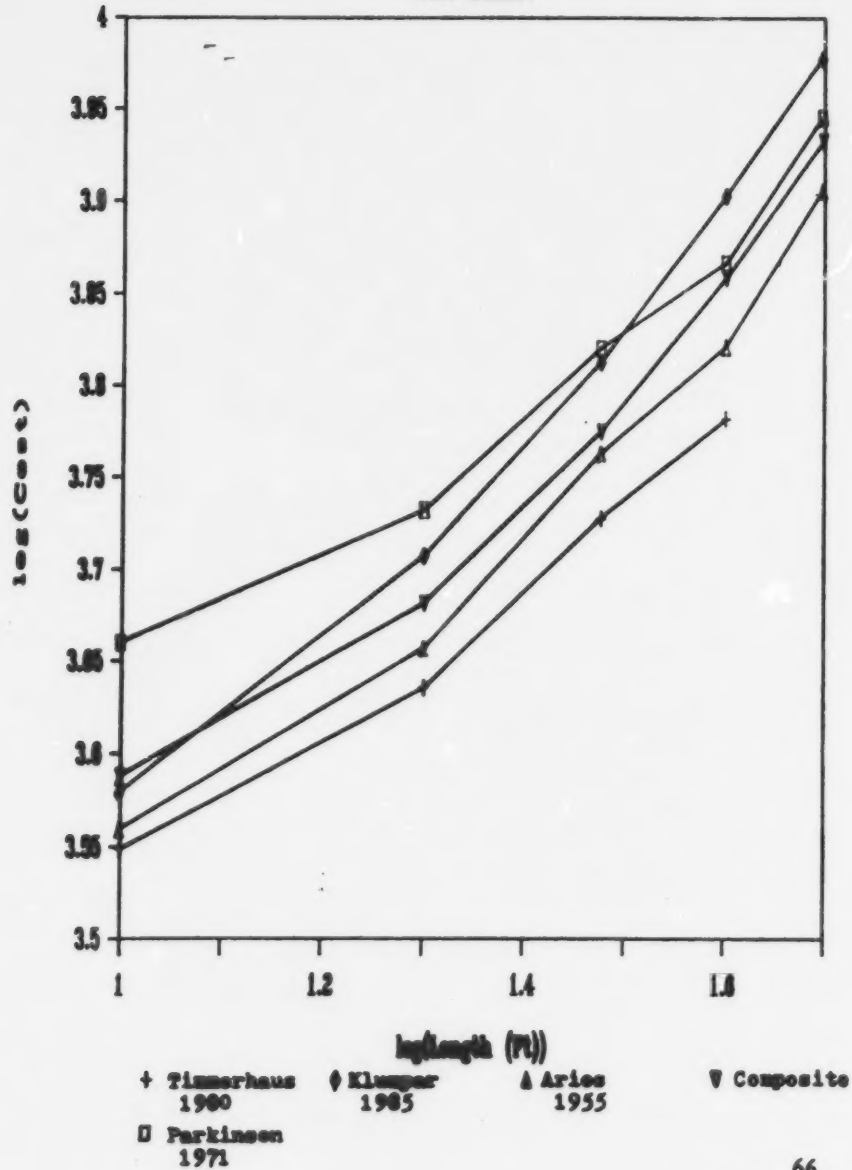


FIGURE 22
12 by 7 Inch Bucket Elevator Costs
1970 Dollars

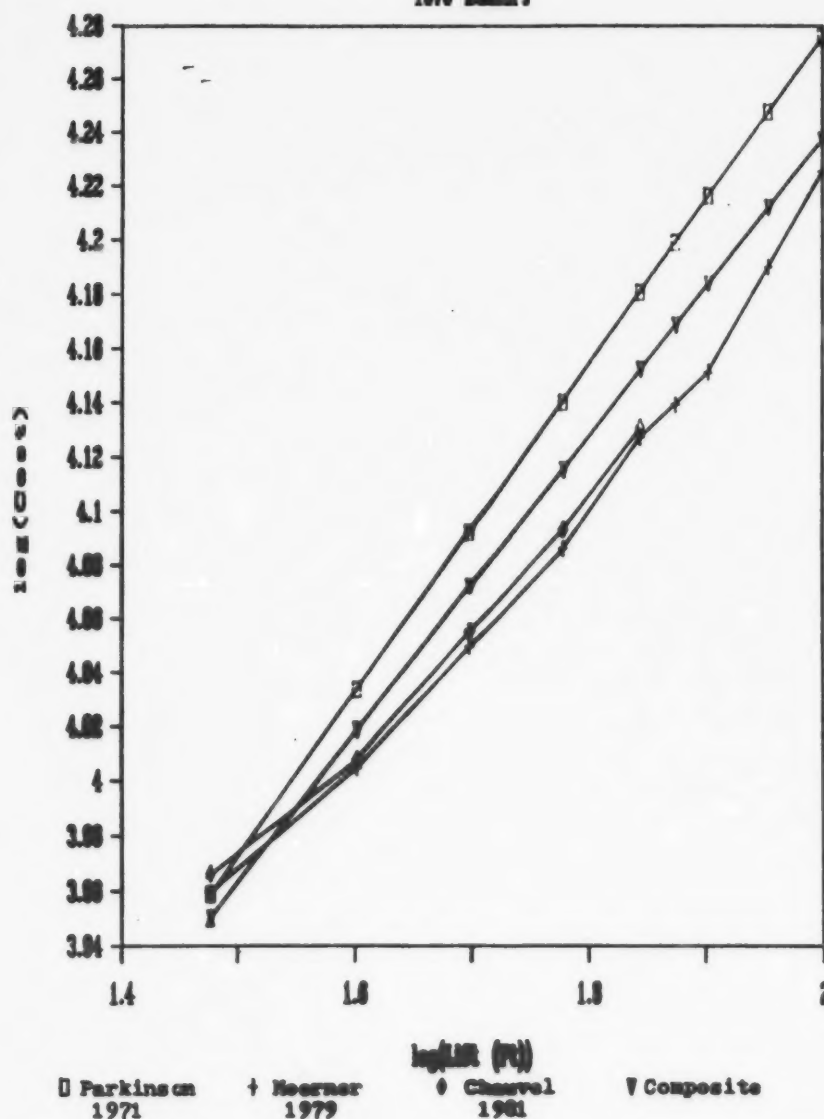


FIGURE 23
10 by 6 Inch Bucket Elevator Costs
1979 Dollars

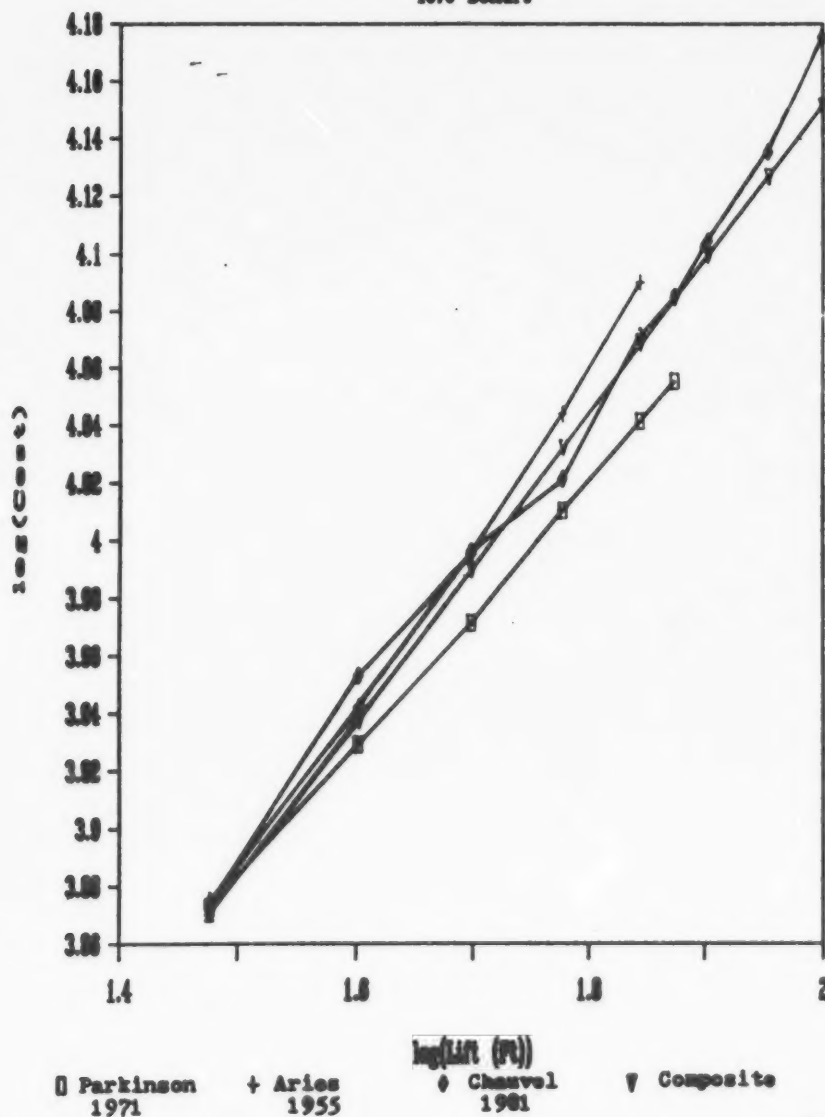


FIGURE 24
Vibrating Screen Costs
1970 Dollars

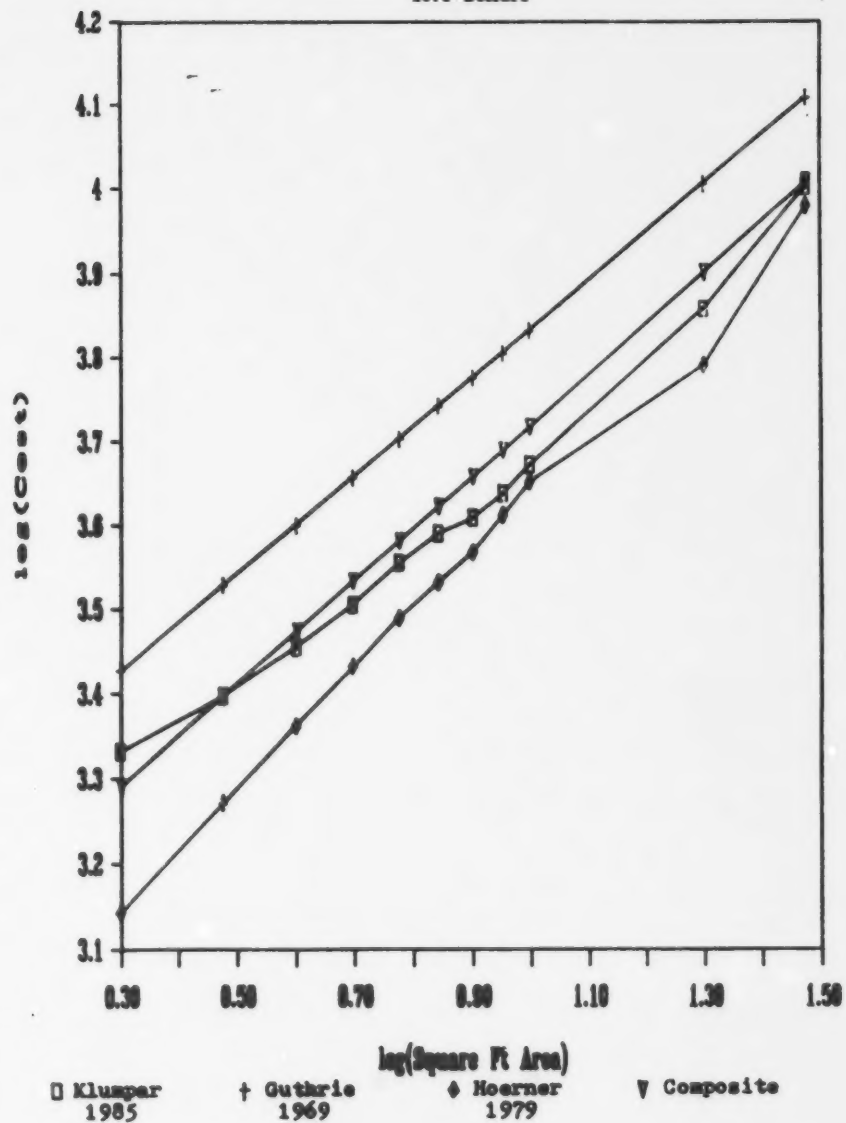


TABLE 3 : Costing Data for Main Plant Items

Boiler : Cost data from Foster-Wheeler

Pumps : Cost data from ASPEN

De-aerator : Cost data from ASPEN

Baghouse : Cost data from ASPEN

Air Compressors : $COST=259*(CAPACITY)**.683$
(Klumpar, 1985)

Bucket Elevators 10" by 6" : $COST=1195*(LIFT)**.537$
(Parkinson, 1971), (Aries, 1955) & (Chauvel, 1981)

Bucket Elevators 12" by 7" : $COST=1378*(LIFT)**.549$
(Parkinson, 1971), (Chauvel, 1981) & (Hoerner, 1979)

Bucket Elevators 16" by 8" : $COST=2010*(LIFT)**.49$
(Parkinson, 1971)

Screw Conveyors 9" diameter : $COST=2746*(LEN)**-.398*((LEN)**.324)$
 $*(LOG(LEN))$
(Aries, 1955), (Chauvel, 1981), (TIMMERHAUS, 1980) & (Klumpar, 1985)

Screw Conveyors 14" diameter : $COST=7458*(LEN)**-.742*((LEN)**.458)$
 $*(LOG(LEN))$
(Parkinson, 1971), (Aries, 1955), (TIMMERHAUS, 1980) & (Klumpar, 1985)

Screw Feeders 6" diameter : $COST=806*(LEN)**.566$
(Guthrie, 1971)

Vibrating Feeders : $COST=.34*(AREA\ IN\ SQUARE\ INCHES)**1.25$
(Parkinson, 1971)

Scraper Conveyor : $COST=1.54*(LEN(FT)*WIDTH(IN))**.9$
(Woods, 1983)

Belt Conveyor : $COST=6100+180*(LEN)$
(Humphreys, 1981)

Vibrating Screen : $COST=1279*(LEN)**.611$
(Hoerner, 1979), (Klumpar, 1985) & (Guthrie, 1969)

Tramp Iron Magnet : $COST=1309*(POWER, kW)$
(Woods, 1983)

NOTE: All costs are in U.S., 1979 dollars.

6.3 FIXED CAPITAL

Many methods exist for estimating the escalation of the delivered costs of the "Main Plant Items" to the total capital required by a project. The procedure outlined in Chapter 2 of the book Basic Cost Engineering by Humphreys and Katell is used in this study. In this procedure the delivered costs of the equipment (found by multiplying the purchased cost by a factor found in Guthrie, (1969)), were multiplied by two factors (Humphreys and Katell (1981)) to produce an installed cost for the equipment. Two more factors, depending on the type of material the equipment handles and the temperature and pressure of operation, Humphreys and Katell (1981), are used to calculate the material and labor costs for the following support facilities for the main plant items, foundations, structures, buildings, insulation, electrical, piping, painting and miscellaneous. Summation of all the installed costs and the cost for the support facilities provides the Total Direct Cost. Five more factors, from Humphreys and Katell (1981), are used to estimate the following five quantities, the Field Indirect Costs, the Engineering Costs, the Overhead and Administration Costs, a Contingency Fund, and the Fees paid to engineering and installation organizations. The summation of all these costs provide the Total Investment Cost. Finally, a provision for working capital must be made. The factor used here came from Timmerhaus (1980). The Total Capital investment is then calculated.

This above sequence has been translated into the computer program seen in Appendix III. An output from this program is provided in Appendix IV. It can be noted that all costs are in late 1985 Canadian dollars.

The accuracy of the above calculation procedure was checked against data found in Friedrich (1982). In that reference, it is stated that the contract awarded to Foster-Wheeler for the construction of the plant addition with two FBC boilers was \$13 million, Canadian dollars. The procedure outlined above gave a construction cost of \$17.8 million Canadian dollars, which represents good agreement.

The costing scheme outlined in Timmerhaus (1980) was used as a check on the accuracy this work. The estimated Total Fixed Capital produced by the two schemes came to within 4% of one another.

6.4 OPERATING EXPENSES

The operating expenses for the plant were obtained from various sources. One of these sources was Mr. V. Razbin. A summary of the data obtained follows:

- Coal cost - C\$25/ton
- Limestone cost - C\$36/ton
- Electricity cost - C\$0.085/kW-hr

- Number of operators - 25
- Average operator salary - C\$23 700/year

A Literature source, Timmerhaus (1980), provided the following data:

- Operating hours - 7 884 hrs/year
- Plant life - 25 years
- Construction time - 4 years
- Makeup water cost - C\$0.0072/454.54 kg

The following assumptions were made based on the current economic conditions:

- Interest rate 12 percent
- 1.35 Canadian dollars per American dollar

The above information was processed in the following manner. First, the heat and material balances were used to calculate the yearly raw material costs for electricity, coal, limestone and make up water for the boiler. The electricity consumption for the Coal and Limestone Preparation Flowsheet is also required. From this process flowsheet it was decided which pieces of equipment would have to be in operation to supply the boiler with fuel and sorbent. The motor sizes of this equipment were then collected from the Foster-Wheeler design manuals. Assuming that the motors were designed to operate at two thirds of rated capacity when the plant was operated at 100% load, the electricity consumption per pound of coal or limestone fed to the bed was calculated for each motor. Total

factors for the coal and limestone preparation schemes were then calculated from their respective parts. These total factors are used by the operating expenses section of the costing computer program.

Next, the number of operators was multiplied by the average salary of an operator to produce the labor costs of the plant. Operating expenses under the headings: Fringe Benefits, Administration, Operating Supplies, Maintenance Supplies, Taxes, Insurance and Other, were calculated using factors from Johnnie and Aggarwal (1977), Humphreys and Katell (1981) and Timmerhaus, (1980). The last operating expense, Loan Repayment, was calculated in the following manner. It was assumed that a loan for the entire Total Fixed Capital of the plant would have to be taken out at a interest rate of 12 percent per annum compounded annually. The amount of the loan would also have to include the first four payments, since during construction no steam would be produced. This makes the loan in the order of \$40 million dollars which is paid back in 29 equal payments.

The Discounted Cash Flow method of economic analysis was used here to describe the economic validity of the plant. This technique is used to choose between alternatives on an economic basis. The two alternatives are, build the plant to provide heating steam or heat the base electrically.

It was assumed that there would be no capital cost involved with electric heating. The only expense in electric heating would be the equivalent heating value in kW/hrs of the plant's steam output. This amounts to about \$17 million Canadian dollars per year, see Appendix IV. Discount-

ing, to the present, a string of 29 yearly payments of \$17 million Canadian dollars gives the discounted cash requirement of this alternative. Summing the present value of buying electric heat during the plant construction phase, the total capital loaned from the bank, and the operating expenses over the 25 year lifetime of the plant provides the discounted cost of building and running the plant for 25 years. It is the difference between these two discounted cash flows that is shown in Appendix IV under the heading of "Savings Over the 25 Year Lifetime of the Plant". The positive sum of \$10 million Canadian dollars shows that construction of the plant is more economic than electrically heating the base. If a company had the \$27 million Canadian dollars required to build the plant on hand, \$65 million Canadian dollars could be saved over the lifetime of the plant.

6.5 SUMMARY

A Fortran model for the economic analysis of fluidized bed combustors has been developed using data from several sources. This model provides the total required capital, the operating expenses and the savings made in the construction and operation of fluidized bed combustors.

In the case of a plant built today at CFB Summerside, assuming 90% availability, 100% load operation, 4 year construction time, 25 year plant life, 1.35 Canadian dollars per U.S. dollar and that the required capital

would have to be borrowed at 12% annually, the following observations have been made:

- Total Capital Required, C\$40 million
- Operating Expenses, C\$11 million/year
- Savings vs. Electric heating over plant lifetime, C\$10 million.

The above observations suggest that fluidized bed combustion is an attractive alternative to electric heating for the base.

7.0 SENSITIVITY ANALYSIS

7.1 Introduction

7.2 Effect of Coal Flow, PSD and Analysis on Carbon Losses

7.3 Effect of Limestone Flow and PSD on Carbon Losses

7.4 Effect of FBC Operating Conditions on Carbon Losses

7.5 Effect of Coal Unit Costs on Process Economics

7.6 Effect of limestone Unit Costs on Process Economics

7.7 Effect of Utility Unit Costs on Process Economics

7.8 Summary

7.1 INTRODUCTION

The sensitivity analysis is a study in a facilities operational behavior. This is accomplished by manipulating variables within the plant and recording the plant's response to these changes. A sensitivity analysis will lead to further understanding of the plant's behavior and often will point to more desirable operating conditions.

While a sensitivity analysis can be done on an operating plant, it is preferable to use a verified computer simulation, such as the one developed in this work, in the study. Reasons for this are:

- Faster results from the simulation
- No off-spec product produced during analysis
- Much less expensive
- More combinations of plant conditions can be studied
- Isolation of manipulated variable

A sensitivity analysis, using the computer model developed at Queen's, for the CFB Summerside steam heating plant, is presented in this chapter.

Computer models can also be used to answer "what if" type questions as well. These can range from small questions such as the closure of a recycle valve, to questions concerning addition of a new processing section, new product specifications, selection of new feed stream compositions or the addition or removal of processing equipment. All of these questions

can be answered quickly and economically by a computer simulation. A simulation can also "pay" for itself in the economic optimization of the plant's operating conditions. The above provides a listing of the benefits delivered by a computer simulation that must be weighed against the cost of such a study. A discussion of the benefits and costs of computer simulation is presented in chapter 8.

For the operational sensitivity analysis we chose the overhead carbon loss as the dependant variable because this is a major contributor to the inefficiency of the plant and seems to be responsive to the way in which the plant is operated. Greater efficiency may be possible with an intelligent choice of operating conditions. Independent variables that are to be studied are:

- coal flow
- coal PSD
- coal analysis
- bed temperature
- combustion air flow
- limestone flow
- limestone PSD

The economic studies were done comparing the savings made in the 29 year lifetime of the project (4 years construction, 25 year plant life) against the cost of heating the base electrically for the same 29 year period. Independent variables studied are:

- coal unit cost
- limestone unit cost
- electricity unit cost

In the following plots the solid lines represent a 1:1 relationship between the dependent and independent variables. This relationship would be termed responsive, any line steeper than this would be termed very responsive, conversely any line flatter is termed non-responsive.

7.2 EFFECT OF COAL FLOW, PSD AND ANALYSIS ON CARBON LOSSES

Figure 25 is a plot of overhead carbon losses vs. coal flow and the ash and water percentage in the coal. As shown in figure 25, the carbon losses are not responsive to either the water or ash percent in the coal. This flat response makes the use of poorer quality fuels in a fluidized bed possible since the performance does not decrease significantly. The fluidized bed's ability to burn fuel of various qualities is the technology's greatest advantage over its competitors. The rapid rise in carbon loss due to a coal feed increase is due, not to the extra coal, but to an increase in superficial gas velocity since the excess air percentage was kept constant. The effect of an increase in superficial gas velocity on carbon losses is outlined later in section 7.4.

FIGURE 25
SENSITIVITY ANALYSIS
 OVERHEAD CARBON LOSS VS COAL PROPERTIES

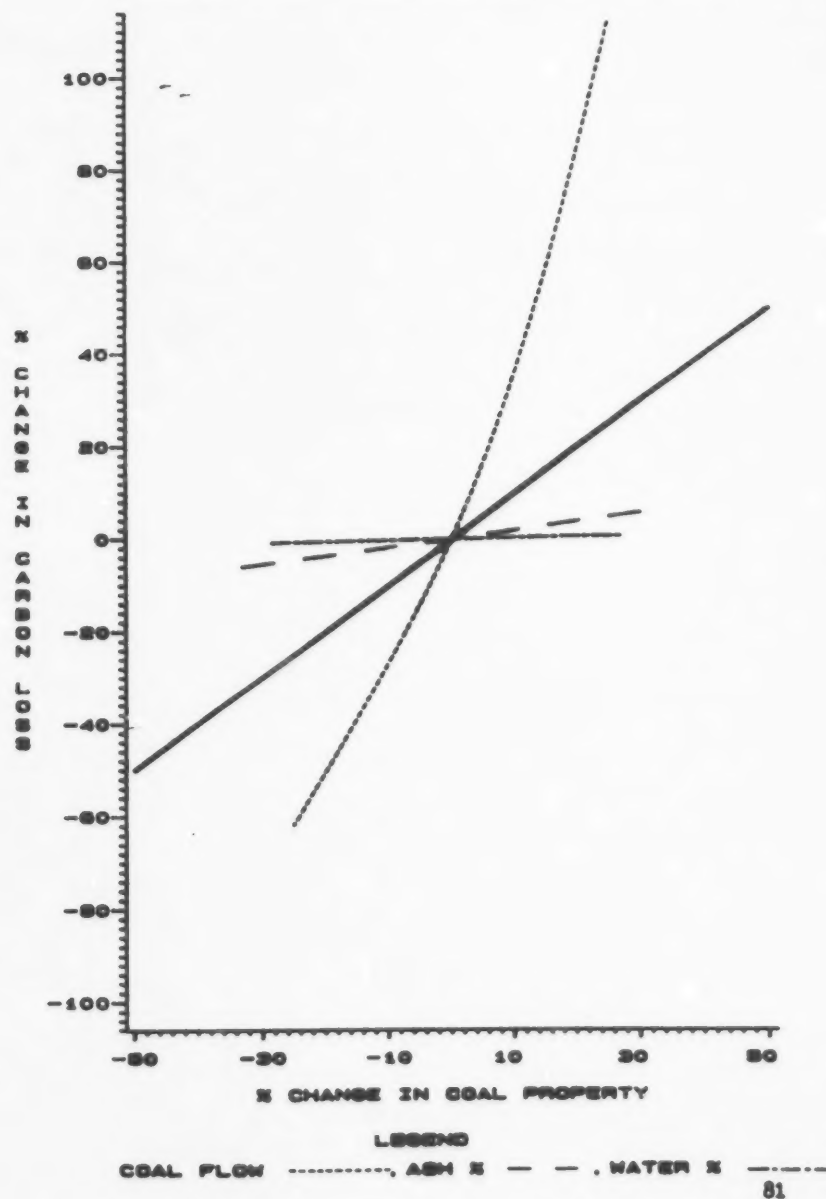


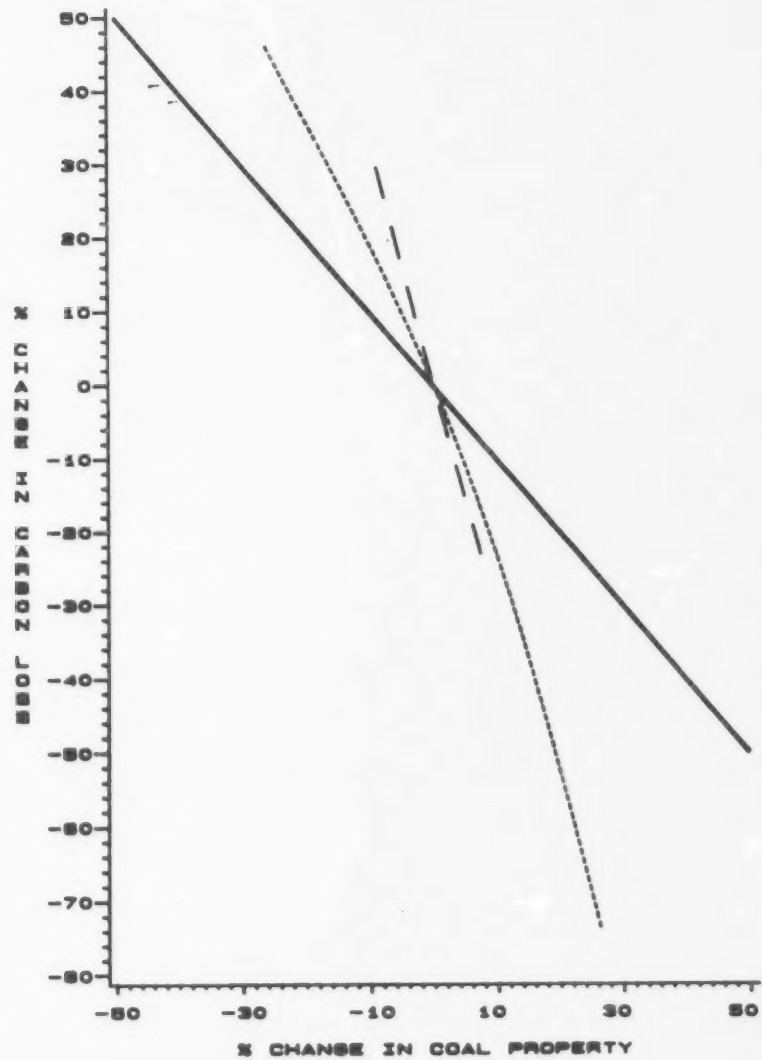
Figure 26 is a plot of overhead carbon losses vs. the carbon in the coal and the average particle diameter of the coal fed to the combustor. Increasing the amount of carbon fed to the bed in the coal feed decreases the overhead carbon loss, as shown by the curve representing an increase in carbon content of the coal, since this promotes lower superficial velocities in the freeboard and higher carbon loading in the bed. The mean diameter of the feed coal particles and the shape of the distribution function play a large role in the efficiency of the combustor. In Figure 26 it can be seen that increasing the average coal particle diameter, without changing the distribution function, gives a large increase in combustion efficiency. This is due to the higher carbon loading in the bed since the larger particles are not elutriable.

What cannot be shown on a graph is the increased efficiency brought about by the alteration of the shape of the coal's PSD through pre-processing. Here the limestone's double screened distribution function, translated to a larger mean particle diameter was used as an example of pre-processing. What this provided was a feed stream of coal with the same mean particle diameter, but a much narrower range than the original feed. Using this coal the overhead carbon losses were reduced to .43% of the normal value. Since a price for double screened coal was not available, an economic study of the viability of using pre-processed coal was not possible but it would be an interesting study.

FIGURE 26

SENSITIVITY ANALYSIS

OVERHEAD CARBON LOSS VS COAL PROPERTIES II



LEGEND

CARBON % - - - - PARTICLE DIAMETER - - - - -

7.3 EFFECT OF LIMESTONE FLOW AND PSD ON CARBON LOSSES

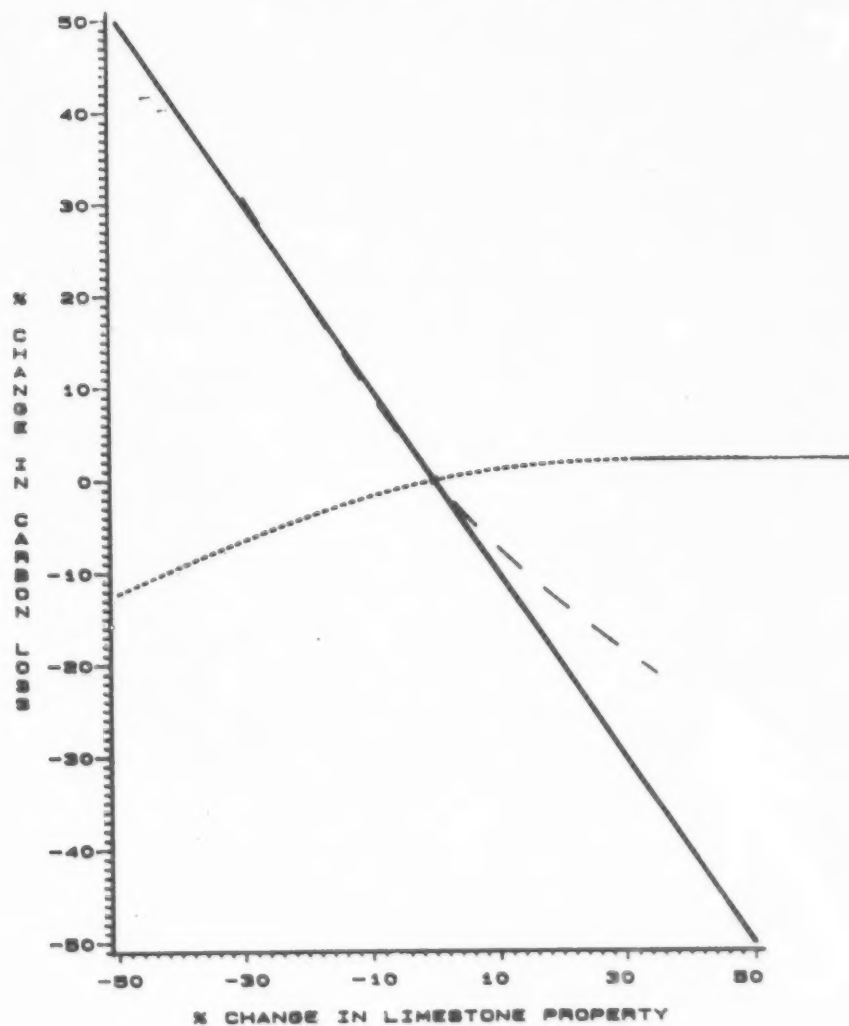
Figure 27 is a plot of overhead carbon loss vs. limestone properties. The shallow line represents limestone flow and it can be seen that carbon losses are not responsive to this variable. The overhead carbon loss is, however, increased by a reduction in the mean particle diameter of the limestone. The flat response of the model to the limestone feed rate is expected and is useful in plant optimization. The flat curve demonstrates that sulfur capture and combustion efficiency are uncoupled. This makes optimization easier since this allows each of the considerations to be optimized separately. The model's responsiveness to limestone PSD changes is unexpected and is explained below. Unfortunately all the limestone feed data we have has the same PSD, therefore the model's response to PSD changes in the limestone feed cannot be validated against plant data. If the model does correctly mimic the plant, this suggests that the increased sulfur capture efficiency of smaller limestone particles would have to be weighed against higher carbon losses.

In the model, the amount of coal leaving the combustor is modelled as being directly related to the elutriation rate of the coal, which is unaffected by the mean particle size in the bed, and the carbon loading in the bed. Here, the carbon loading in the bed is assumed to be the same as that in the bed drains which is calculated by the equation from Anthony, et al., (1985). In this equation, a decrease in average bed particle size, which is directly related to the average limestone particle size fed, will produce a decrease in the carbon losses to the bed drain

FIGURE 27

SENSITIVITY ANALYSIS

OVERHEAD CARBON LOSS VS LIMESTONE PROPERTIES



LEGEND

LIMESTONE FLOW ——— MEAN PARTICLE DIAMETER - - -

and hence a lower carbon loading in this stream. Therefore a decrease in the mean diameter of the limestone feed will produce lower carbon loading in the bed which will decrease the overall efficiency of the plant. In the model, decreases in plant efficiency always show up in an increase in the overhead carbon loss.

7.4 EFFECT OF FBC OPERATING CONDITIONS ON CARBON LOSSES

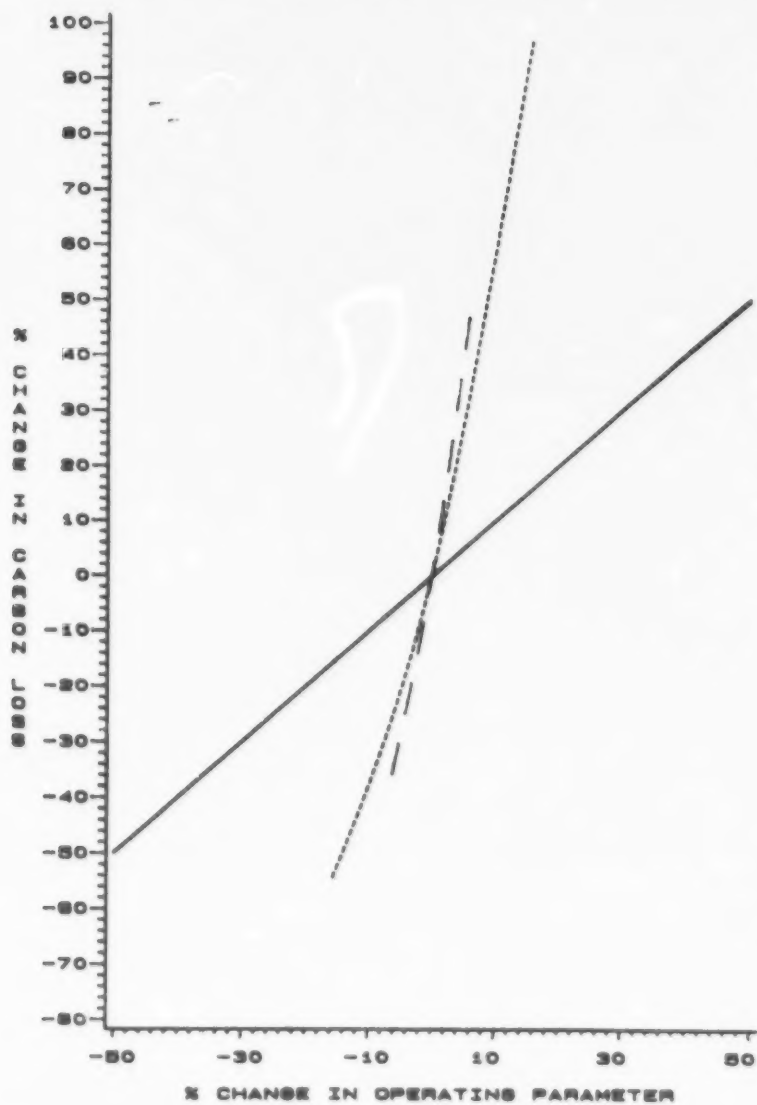
Figure 28 is a plot of carbon loss vs. bed operating conditions. From this diagram it is obvious that both the air flow and the bed temperature have a large direct effect on the carbon loss. Both of these phenomena are a result of an increase in the superficial velocity in the freeboard. In the case of increased air flow, it is simply the increased mass of air that causes the increase in superficial velocity. The higher bed temperature decreases the density of the fluid and therefore for the same mass flowrate an increased volumetric flow is observed. This increased volumetric flow causes an equal increase in superficial velocity.

It should be noted that in both of these cases some increase in the reaction rate, hence a decrease in carbon loss, would occur at the plant. While the absolute magnitude of any changes in reaction rate due to temperature changes is unknown, the reaction rate at the surface of the char particle increases 4 fold (Congalidis (1981)) over the bed temperature range studied in the sensitivity analysis. The change in reaction

FIGURE 28

SENSITIVITY ANALYSIS

OVERHEAD CARBON LOSS VS OPERATING PARAMETERS



LEGEND

AIR FLOW ----- BED TEMP - - - -

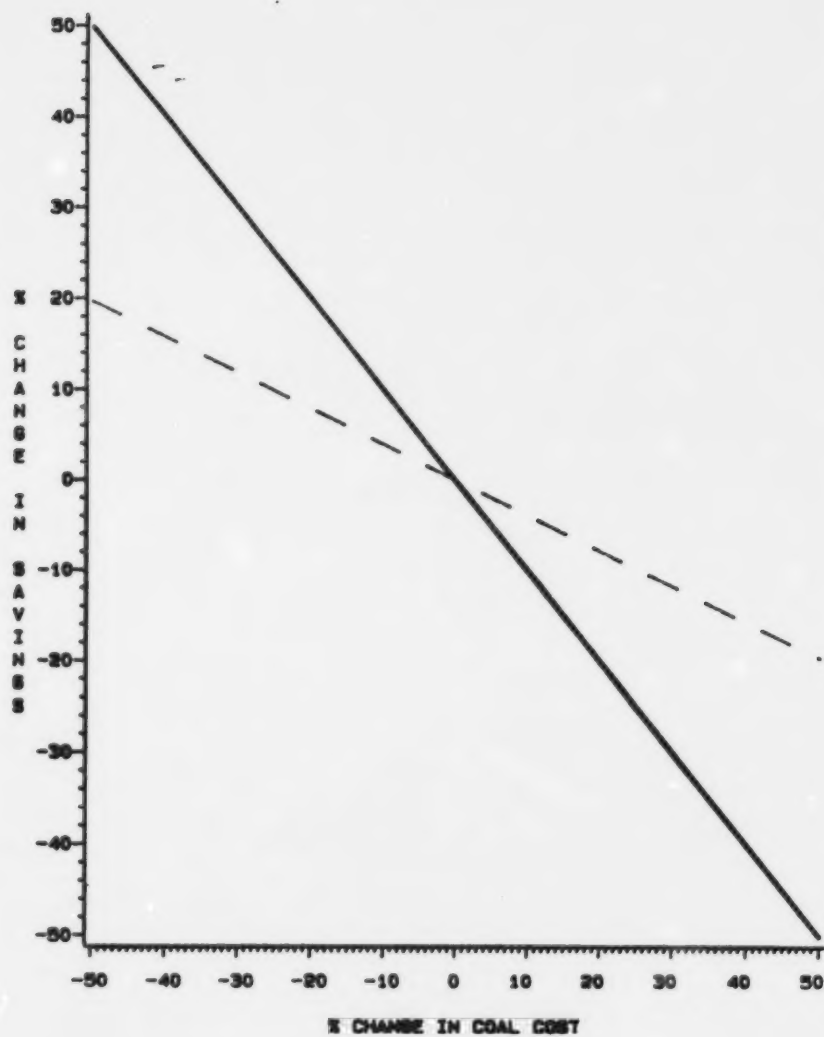
rate due to increased oxygen concentration in the fluidized bed is believed to be smaller than that for temperature changes. The model assumes a constant reaction rate, thus the steepness of these curves is exaggerated. Even so, we believe that the carbon loss is very responsive to the air feed rate.

These results suggest that the plant should be run at the lowest air feed rate possible to promote high combustion efficiencies. Operation at these conditions would lead to poor mixing in the bed, lower heat transfer rates and possibly the formation of clinker. This leads to a trade-off between economics and operational stability.

7.5 EFFECT OF COAL UNIT COSTS ON PROCESS ECONOMICS

Figure 29 is a plot of change in discounted savings vs. a change in the price of coal. From the plot it is seen that the economics is somewhat responsive to coal costs. This effect is damped by the large Loan Repayment (over 61% of the total yearly expenses) that is required each year. If interest charges are neglected, the coal price has a significant inverse effect on the economic viability of this process.

FIGURE 29
SENSITIVITY ANALYSIS
SAVINGS VS COAL PRICE



7.6 EFFECT OF LIMESTONE UNIT COSTS ON PROCESS ECONOMICS

Figure 30 is a plot of change in discounted savings vs. a change in the price of limestone. From the plot it is seen that the economics is not responsive to limestone costs due to the small input of limestone that is required to give adequate sulfur capture. This effect is also damped by the large Loan Repayment and the effect of neglecting interest payments would be approximately the same here as it was for the coal.

7.7 EFFECT OF UTILITY UNIT COSTS ON PROCESS ECONOMICS

Figure 31 is a plot of change in savings vs. change in utilities cost. The utility referred to in the figure is electricity. Since the viability of the combustor is being compared with the cost of electric heating, it is expected that a small decrease in the price of electricity would have a very large negative effect on the relative economics of the plant. Such is the case in Figure 31. This plot may lead one to have reservations about the viability of the plant when subject to a reduction in power costs, but it is more probable that the price of electricity will go up, relative to that of coal, especially in an area that has no hydro-electric power, thus improving the overall economics of the process.

FIGURE 30
SENSITIVITY ANALYSIS
SAVINGS VS LIMESTONE PRICE

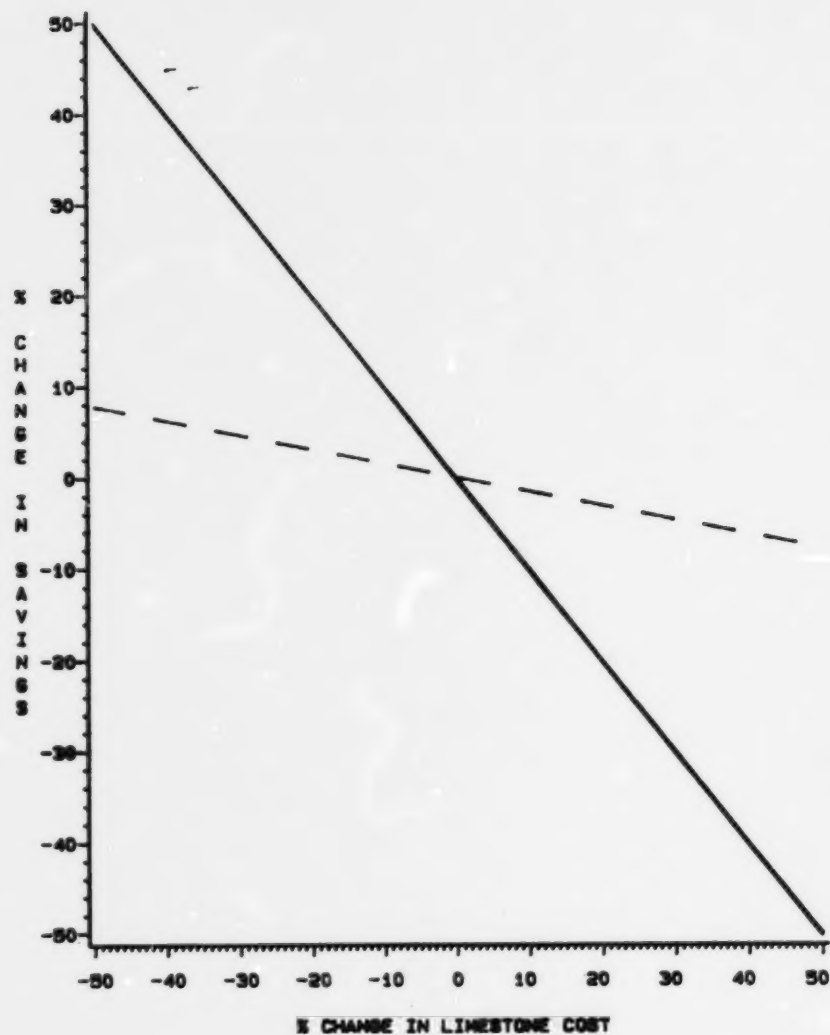
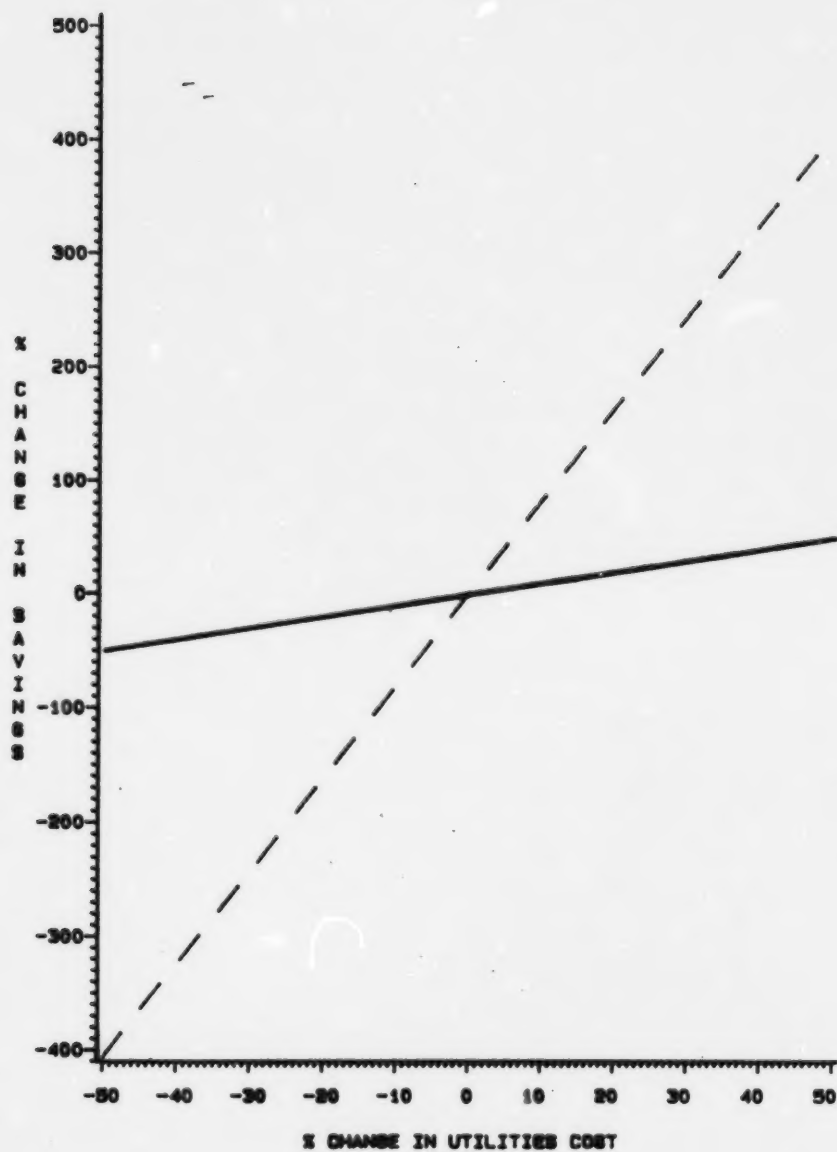


FIGURE 31
SENSITIVITY ANALYSIS
SAVINGS VS UTILITIES PRICE



7.8 SUMMARY

The operational and economic tendencies of the plant have been described.

The plant is very responsive to the following parameters:

- Air flow
- Coal mean particle diameter
- Coal Particle size distribution function

The recommendations for the most efficient operation of the plant are what was expected. Run the plant with:

- little or no excess air
- a very narrow size range of large coal particles

While operating the plant at the above conditions is probably not feasible, using the above guidelines as targets will lead to increased combustion efficiency.

The economics of the plant is not responsive to the coal and limestone costs due to the large loan repayment that constitutes over 61% of the annual expenses of the plant. The electricity cost, since electric heating is the base case for comparison, effects the plant's economics greatly. This may be an asset since an increase in electricity costs (much more probable than a decrease) will lead to a greater relative savings for the coal burning installation.

8.0 ASSESSMENT OF INCENTIVES FOR IMPROVED PROCESS SIMULATION

Using the modern, large scale process simulation system ASPEN, the CFB Summerside AFBC steam heating plant has been simulated at the heat and material balance level and an economic analysis has been performed.

The ASPEN model, validated with plant data, took 2 years to develop at a cost of \$85,000.

The ASPEN model is powerful and comprehensive. It can be easily modified to incorporate different FBC models or operating conditions, such as different coals and/or limestones. The model can now be used to test the effect of different operating strategies or design modifications on the operation and economics of the plant.

The incentives for using the model are to save time and money. The model may be used to plan an experimental program by examining a range of different operating conditions and testing those which appear interesting. This approach will eliminate the need to perform unprofitable tests at a significant cost.

The model may be used to find a better set of operating conditions. For example, if it is possible to reduce the operating costs by 10%, this will result in a savings of about \$1.1 million per year! Similarly, a reduction in the capital cost of a new plant of 10% would yield a savings of about \$2.5 million.

By using the simulation model as a tool to examine different design and operating scenarios, significant savings may be realized for a nominal cost.

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APPENDIX I - ASPEN INPUT FILE

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NEW
TITLE 'STREAM ATTRIBUTE MANIPULATION 16/07/88'
DESCRIPTION "TESTING OF ACCESSING OF ATTRIBUTE VARIABLES
              (ULTIMATE AND PROXIMATE ANALYSIS AND PSD)
              FOR LATER USE IN FORTRAN BLOCKS"

```

```

;
OUT-UNITS ENG ENERGY-FLOW = WATT
HISTORY MSG-LEVEL PROPERTIES=2
RUN-CONTROL MAX-TIME=10000.
;

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```

STREAM-REPORT
  STANDARD OPTIONS=MASS-FLOW
;

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;
*****
;

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FLWSHEET : SOLIPREP

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;
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;

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FLWSHEET SOLIPREP

SCRNC	IN=FEEDC	OUT=POSTSCTC	POSTSCBC
CRUSHC	IN=POSTSCTC	OUT=POSTCRUC	
MIXC	IN=POSTSCBC	POSTCRUC	OUT=COAL
MULT1	IN=COAL	OUT=BEDCOAL	
SCRNL	IN=FEEDL	OUT=POSTSCTL	POSTSCBL
CRUSHL	IN=POSTSCTL	OUT=POSTCRUL	
MIXL	IN=POSTSCBL	POSTCRUL	OUT=LIME
MULT2	IN=LIME	OUT=BEDLIME	
MIXTOT	IN=BEDCOAL	BEDLIME	OUT=DUMFEED

```

;
*****
;

```

FLWSHEET : COMBUST

```

;
*****
;

```

FLWSHEET COMBUST

FDFA	IN=AIRFEED	OUT=COMBAIR	FDDRAW
MIX1	IN=COMBAIR	PREFEED	H2OF
DEVOL	IN=RAWFEED	OUT=BEDFEED	VOLHT
BEDHEAT	IN=BEDFEED	OUT=BEDIN1	BEDHT
BEDCAL	IN=BEDIN1	OUT=BEDIN2	CALHT
BEDSUL	IN=BEDIN2	OUT=BEDIN3	SULHT
SEP1	IN=BEDIN3	OUT=BEDSOL	BEDGAS
BEDCOOL	IN=BEDGAS	OUT=BEDOUT	COOLHT
DRAINCL	IN=BEDSOL	OUT=ASHCOOL	DRAINHT
HTSPLIT	IN=DRAINHT	OUT=SBDDUTY	PBDDUTY
ECONO	IN=BEDOUT	OUT=TOBAG	ECONOHT
BAGHOUSE	IN=TOBAG	OUT=GASCLN	TOASH
IDFA	IN=GASCLN	OUT=TOSTACK	IDDRAW
HTMIX	IN=VOLHT	BEDHT	CALHT
	SULHT	COOLHT	OUT=BOILERHT

```

;
*****
;

```

FLWSHEET : STEAM

FLWSHEET STEAM

HOTTANK	IN=COND MAKEUP CRETURN	OUT=D1
SPLIT1	IN=D1	OUT=COOL LPRETURN
DUTY1	IN=COOL	OUT=COOL2 MIXLOSS
CWPUMP	IN=COOL2	OUT=FDRAIN CWDRAW
SPLIT2	IN=FDRAIN	OUT=SCOOLIN PCOOLIN
SBDcool	IN=SCOOLIN SBDDUTY	OUT=SCOOLOUT
PBDcool	IN=PCOOLIN PBDDUTY	OUT=PCOOLOUT
MIX2	IN=SCOOLOUT PCOOLOUT	OUT=CRETURN
CRPUMP	IN=LPRETURN	OUT=HPRETURN CRDRAW
AERMIX	IN=HPRETURN AERSPLY	OUT=LPFEED
BFPUMP	IN=LPFEED	OUT=HPFEED BFDRAW
ECONOS	IN=HPFEED ECONOHT	OUT=FEED
BEDSPLIT	IN=FEED	OUT=BOILFEED BDOWN
BOILER	IN=BOILFEED BOILERHT	OUT=STEAM2
AERSPLIT	IN=STEAM2	OUT=PLANT DUMMY
HEATLOSS	IN=BDOWN	OUT=BCOOL BLOSS

COMPONENTS & PHYSICAL PROPERTIES

COMPONENTS S02 O2S/NO2 NO2/O2 O2/CO2 CO2/N2 N2/WATER H2O/
COAL/SIO2 SIO2/CAO CAO/CASO4 CASO4/
CACO3 CAC03

FORMULA CO2 CO2/N2 N2/WATER H2O

PROPERTIES SYSOP0 SOLIPREP COMBUST /SYSOP12 STEAM

PROP-DATA

PROP-LIST MW 1/ DHSFRM 1/ DGSFRM 1
PVAL CAO 56.08/ -.64879E9/ -.603E9
PVAL CASO4 136.14/ -1.4585E9/ -1.297E9
PVAL CAC03 100.09/ -1.2317E9/ -1.134E9
PVAL SIO2 60.08/ -.84833E9/ -.797E9

PROP-LIST CPSP01 1
PVAL CAO 41.9E3 20.3 0. 0. -452.E6 273. 2000.
PVAL CASO4 77.5E3 92.0 0. 0. -665.E6 273. 2000.
PVAL CAC03 82.4E3 49.8 0. 0. -1.29E9 273. 2000.
PVAL SIO2 27.7E3 11.2 0. 0. -2.19E9 273. 2000.

PROP-LIST VSPOLY 1
PVAL CAO 1.69E-2 0. 0. 0. 0. 2000.
PVAL CASO4 4.60E-2 0. 0. 0. 0. 2000.
PVAL CAC03 3.57E-2 0. 0. 0. 0. 2000.
PVAL SIO2 1.21E-2 0. 0. 0. 0. 2000.

NC-PROPS COAL ENTHALPY HCOALGEN/DENSITY DCHARIGT

;
;
;

STREAM SECTION

DEF-STREAMS HEAT SBDDUTY PBDDUTY ECONOHT BOILERHT MIXLOSS BLOSS &
VOLHT BEDHT CALHT SULHT COOLHT DRAINHT

DEF-STREAMS ELECTRICITY CRDRAW CWDRAW FDDRAW IDDRAW BFDRAW

DEF-STREAM-CLASS SOLID

DEFINITION SUBSTREAMS=MIXED CIPSD NCPSD

DEF-STREAMS SOLID FEEDC POSTSCTC POSTSCBC POSTCRUC BEDCOAL &
FEEDL POSTSCTL POSTSCBL POSTCRUL BEDLIME PREFEED &
AIRFEED BEDFEED BEDIN1 BEDIN2 BEDIN3 DUMFEED &
BEDOUT BEDSOL BEDGAS H2OF RAWFEED COAL LIME &
TOBAG ASHCOOL COMBAIR GASCLN TOASH TOSTACK

DEF-SUBS-ATTR PSD PSD

IN-UNITS LENGTH=MU

INTERVALS 35

SIZE-LIMITS 0/20/40/60/80/100/150/200/250/300/350/400/450/500/
600/700/800/900/1000/1500/2000/2500/3000/4000/5000/6000/
7000/8000/9000/10000/15000/20000/25000/30000/35000/40000

ATTR-COMPS COAL PROXANAL ULTANAL SULFANAL

STREAM AIRFEED

SUBSTREAM MIXED TEMP=56.84 PRES=14.696 MASS-FLOW=46617.0

MOLE-FRAC O2 .21/N2 .79

STREAM H2OF

SUBSTREAM MIXED TEMP=69. PRES=16.74344 MASS-FLOW=6.8453

MOLE-FRAC WATER 1.0

SUBSTREAM CIPSD TEMP=69. PRES=16.74344 MASS-FLOW=.000001

MASS-FRAC CACO3 1.0

SUBSTREAM NCPSD TEMP=69. PRES=16.74344 MASS-FLOW=.000001

MASS-FRAC COAL 1.0

COMP-ATTR COAL PROXANAL (6.9 43.2 30.2 19.7)/

ULTANAL (19.7 57.44 4.0 1.21 0.0 4.65 6.1)/

SULFANAL (1.97 .08 2.60)

STREAM FEEDC

SUBSTREAM MIXED TEMP=69. PRES=16.74344 MOLE-FLOW=.0001

MOLE-FRAC N2 .79/O2 .21

SUBSTREAM CIPSD TEMP=69. PRES=16.74344 MASS-FLOW=.0001

MASS-FRAC CACO3 1.0

SUBS-ATTR PSD FRAC=0.0 0.0 0.0 0.0 0.0 0.0 0.00125 .00175 &
.002 .0025 .0034 .0039 .0052 .012 .018 &
.015 .07 .065 .36 .24 .13 .038 .029 .003 &
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

SUBSTREAM NCPSD TEMP=69. PRES=16.74344 MASS-FLOW=25000.
 MASS-FRAC COAL 1.0
 COMP-ATTR COAL PROXANAL (7.95 47.65 31.37 13.04)/
 ULTANAL (13.04 62.69 4.08 1.09 0.0 4.4 6.75)/
 SULFANAL (1.85 .08 2.47)
 SUBS-ATTR PSD FRAC=0.0 0.0 0.0 0.0 0.0 .0048 .0006 .001 .0015 &
 .0011 .0015 .0015 .0013 .0028 .0029 .0035 &
 .0035 .0035 .0155 .015 .016 .019 .035 .044 .06 &
 .056 .054 .056 .06 .23 .15 .1 .042 .0145 .0035

;
 STREAM FEEDL

SUBSTREAM MIXED TEMP=69. PRES=16.74344 MOLE-FLOW=.0001
 MOLE-FRAC N2 .79/02 .21
 SUBSTREAM CIPSD TEMP=69. PRES=16.74344 MASS-FLOW=25000.
 MASS-FRAC CaCO3 .948/SiO2 .052
 SUBS-ATTR PSD FRAC=0.0 0.0 0.0 0.0 0.0 0.0 .00125 .00175 &
 .002 .0025 .0034 .0039 .0052 .012 .018 &
 .015 .07 .065 .36 .24 .13 .038 .029 .003 &
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
 SUBSTREAM NCPSD TEMP=69. PRES=16.74344 MASS-FLOW=.0001
 MASS-FRAC COAL 1.0
 COMP-ATTR COAL PROXANAL (7.95 47.65 31.37 13.04)/
 ULTANAL (13.04 62.69 4.08 1.09 0.0 4.4 6.75)/
 SULFANAL (1.85 .08 2.47)
 SUBS-ATTR PSD FRAC=0.0 0.0 0.0 0.0 0.0 .0048 .0006 .001 .0015 &
 .0011 .0015 .0015 .0013 .0028 .0029 .0035 &
 .0035 .0035 .0155 .015 .016 .019 .035 .044 .06 &
 .056 .054 .056 .06 .23 .15 .1 .042 .0145 .0035

;
 STREAM PREFEED

SUBSTREAM MIXED TEMP=69. PRES=16.74344 MOLE-FLOW=.0001
 MOLE-FRAC N2 .79/02 .21
 SUBSTREAM CIPSD TEMP=69. PRES=16.74344 MASS-FLOW=2246.0
 MASS-FRAC CaCO3 .9793/SiO2 .0207
 SUBS-ATTR PSD FRAC=0.0065 .0035 .0025 .0025 .0025 .002 .0005 &
 .0012 .0012 .0012 .0012 .0012 .0012 .0009 &
 .0009 .001 .04 .13 .40 .30 .08 .004 .004 &
 .002 .002 .002 .003 .002 .002 0.0 0.0 0.0 0.0 0.0
 SUBSTREAM NCPSD TEMP=69. PRES=16.74344 MASS-FLOW=4871.0
 MASS-FRAC COAL 1.0
 COMP-ATTR COAL PROXANAL (6.9 43.2 30.2 19.7)/
 ULTANAL (19.7 57.44 4.0 1.21 0.0 4.65 6.1)/
 SULFANAL (1.97 .08 2.60)
 SUBS-ATTR PSD FRAC=0.013 .007 .006 .004 .005 .01 .007 .007 .006 &
 .005 .005 .004 .004 .007 .008 .005 .007 .005 &
 .015 .01 .04 .05 .06 .04 .05 .07 .08 .06 .06 &
 .22 .10 .02 .01 0.0 0.0

;
 STREAM COND TEMP=160. PRES=14.696
 MASS-FLOW WATER 32754.

;
 STREAM MAKEUP TEMP=80. PRES=14.696


```

CONV 2 NCPSD COAL .050
STOICH 3 NCPSD COAL -2./MIXED O2 -.5/WATER 1
CONV 3 NCPSD COAL .043
STOICH 4 NCPSD COAL -14./MIXED N2 .5
CONV 4 NCPSD COAL .013
STOICH 5 NCPSD COAL -16./MIXED O2 .5
CONV 5 NCPSD COAL .066
;
BLOCK BEDHEAT RSTOIC
PARAM PRES=-57.20[IN-WATER] TEMP=1575.0
STOICH 1 NCPSD COAL -12./MIXED O2 -1/CO2 1
CONV 1 NCPSD COAL .58615
;
BLOCK BEDCAL RSTOIC
PARAM PRES=0.0 TEMP=1575.0
STOICH 1 CIPSD CACO3 -1/CAO 1/
      MIXED CO2 1
CONV 1 CIPSD CACO3 1.0
;
BLOCK BEDSUL RSTOIC
PARAM PRES=0.0 TEMP=1575.0
STOICH 1 CIPSD CAO -1/CASO4 1/
      MIXED SO2 -1/O2 -.5
CONV 1 MIXED SO2 .9
;
BLOCK SEP1 SSPLIT
FRAC MIXED BEDGAS 1.0
FRAC CIPSD BEDSOL 1.0
FRAC NCPSD BEDSOL 1.0
;
BLOCK BEDCOOL HEATER
PARAM TEMP=520.0 PRES=0.0
;
BLOCK DRAINCL HEATER
PARAM TEMP=250.0 PRES=14.696
;
BLOCK HTSPLIT FSPLIT
FRAC SBDDUTY .6537/PBDDUTY .3463
;
BLOCK ECONO HEATER
PARAM TEMP=350.0 PRES=-6.32[IN-WATER]
;
BLOCK BAGHOUSE FABFL
PARAM O 1
BAG-PROPS 12 1 NBAG=36 ABAG=11.338
OPER DPMX=6.0[IN-WATER] TFLT=1.0
;
BLOCK IDFAN COMPR
PARAM TYPE=1 PRES=14.696
;
BLOCK HTMIX MIXER
;
;*****
;
;

```

STEAM FLOWSHEET BLOCKS

```

;
;*****
;
;BLOCK HOTTANK MIXER
;
;BLOCK SPLIT1 FSPLIT
;    MASS-FLOW COOL 35000.
;    R-FRAC LPRETURN 1.0
;
;BLOCK DUTY1 HEATER
;    PARAM PRES=0.0 TEMP=149.
;
;BLOCK CWPUMP PUMP
;    PARAM PRES=39.696
;
;BLOCK SPLIT2 FSPLIT
;    FRAC SCOO LIN .5/PCOO LIN .5
;
;BLOCK SBDCOOL HEATER
;    PARAM PRES=14.696
;
;BLOCK PBDCOOL HEATER
;    PARAM PRES=14.696
;
;BLOCK MIX2 MIXER
;
;BLOCK CRPUMP PUMP
;    PARAM PRES=19.696
;
;BLOCK AERMIX MIXER
;    BLOCK-OPTIONS HMB-RESULTS=2
;
;BLOCK HEATLOSS HEATER
;    PARAM TEMP=80. PRES=14.7
;
;BLOCK BFPUMP PUMP
;    PARAM PRES=214.696 TYPE=1
;
;BLOCK ECONOS HEATER
;    PARAM PRES=-13.9
;
;BLOCK BEDSPLIT FSPLIT
;    MASS-FLOW BDOWN 200.
;
;BLOCK BOILER HEATER
;    BLOCK-OPTIONS HMB-RESULTS=2
;    PARAM PRES=154.696
;
;BLOCK AERSPLIT FSPLIT
;    FRAC DUMMY .041/PLANT .959
;
;*****
;

```

FORTRAN PROGRAMMING

```

:
:
:*****
:
:
FORTRAN AAA
F      COMMON /USER1/OUTCL, FLOW1, OVER, F1, F2
F      REAL*8 ERC(35), I(35,35), MOVERF, JOVERF, DP(35), TOT, OVER,
F      C F, TOT, TOT2, J, K2(35), K4(35), UO, ZBAR, AK1TOT, K2TOT,
F      C K4TOT, WL, FLOW, FLOW1, FLOW2, RHOSL, ERCL(35), RHOG, PE(35),
F      C UT(35), REP(35), CDREP(35), MU, G, RHOS, KCOMP(35), INT, WC, THETA,
F      C TEST, ERR, OUTCL, F1(35), F2(35), SUMPS, FAC, RATE, WB, PHI(35),
F      C DPMEAN, CATOS, SA,
F      C EFFL(35), EFFC(35), R
F      INTEGER K, L, FLAG, FLAG1, BFLAG
F      DATA DP/.002, .004, .006, .008, .01, .015, .020, .025, .030, .035, .040,
F      C .045, .05, .06, .07, .08, .09, .1, .15, .2, .25, .3, .4, .5, .6, .7, .8, .9,
F      C 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0/
F      DATA BFLAG/2/, RHOSL/3.6/
F      DATA MU /4.45E-4/, G /981.0/, RHOG /3.19E-4/, RHOS /2.27/
F      DATA DPC/.002/, R/1.0/
F      DATA FAC/.16/, RATE/9.0/
F      DEFINE FCL MASS-FLOW STREAM=PREFEED SUBSTREAM=NCPSD COMPONENT=COAL
F      DEFINE FLI MASS-FLOW STREAM=PREFEED SUBSTREAM=CIPSD COMPONENT=CAC03
F      DEFINE FAI MASS-FLOW STREAM=PREFEED SUBSTREAM=CIPSD COMPONENT=SI02
F      DEFINE FO2 MOLE-FLOW STREAM=AIRFEED SUBSTREAM=MIXED COMPONENT=O2
F      DEFINE FN2 MOLE-FLOW STREAM=AIRFEED SUBSTREAM=MIXED COMPONENT=N2
F      DEFINE FH2O MOLE-FLOW STREAM=H2OF SUBSTREAM=MIXED COMPONENT=WATER
F      VECTOR-DEF PROX COMPONENT-ATTR STREAM=PREFEED SUBSTREAM=NCPSD &
F      COMPONENT=COAL ATTRIBUTE=PROXANAL
F      VECTOR-DEF ULT COMPONENT-ATTR STREAM=PREFEED SUBSTREAM=NCPSD &
F      COMPONENT=COAL ATTRIBUTE=ULTANAL
F      VECTOR-DEF FO SUBSTRM-ATTR STREAM=PREFEED SUBSTREAM=CIPSD &
F      ATTRIBUTE=PSD
F      VECTOR-DEF AK1 SUBSTRM-ATTR STREAM=PREFEED SUBSTREAM=NCPSD &
F      ATTRIBUTE=PSD
F      DEFINE SCONV7 BLOCK-VAR BLOCK=BEDSUL SENTENCE=CONV VARIABLE=CONV ID1=1
F      DEFINE TEMPP BLOCK-VAR BLOCK=BEDSUL SENTENCE=PARAM VARIABLE=TEMP
F      IF(BFLAG.NE.1) GO TO 403
F      WL=1965454.0
F      SA=35424.0
F      WC=25081.0
F      GOTO 405
F 403 WL=4186576.0
F      SA=75456.0
F      WC=53424.0
F 405 WB=WL+WC
F      WRITE(NHSTRY,*) FCL, FLI, FO2, FN2, FH2O, TEMPP, FAI
F      FC02=ULT(2)*FCL/1200.*.96+FLI/100.
F      FN2 =FN2+FCL*ULT(4)/2800.
F      FH2O=FN2+FCL*ULT(3)/200.
F      FO2A=FO2-FCL*(ULT(2)*.96/1200.+ULT(6)/3206.+ULT(3)/400.)
F      THETA=FO2/(FO2-FO2A)
F      AVGMW=(FC02*44.+FN2*28.+FH2O*18.+FO2A*32.)/(FC02+FN2+FH2O+FO2A)
F      UO=AVGMW*(FC02+FN2+FH2O+FO2A)/3600./(AVGMW/.7302/(460.+TEMPP))

```

```

F      C      *30.48**3/SA
F      WRITE(NHSTRY,*) FC02,FN2,FH2O,F02A,THETA,AVGMW,U0
;
;      IF BFLAG=1 ONLY PREFERENTIAL BED USED. BFLAG=2 INDICATES
;      BOTH BEDS IN OPERATION.
;
;      CALCIUM TO SULFUR RATIO CALCULATION
;
F      CATOS =(FLI/100.08)/(FCL*ULT(6)/100./32.064)
F      IF(CATOS.LE.3.5) GOTO 138
F      Y=.95
F      GOTO 139
;
;      SULFUR CAPTURE CALCULATION: LEAST SQUARES ESTIMATION OF
;      TRIALS DATA FROM SUMMERSIDE COMBUSTOR
;
F 138 Y=(74.0+5.51*CATOS)/100.
;
;      CALCULATION OF UNDERBED WITHDRAWAL CORRECTION
;
F 139 SCONV7=Y
F      DO 512 L=1,35
F          IF(L.LE.6) GO TO 510
F          PHI(L)=124.0*DP(L)**1.9047
F          IF(L.LE.25) GO TO 512
F          PHI(L)=50.0
F          GO TO 512
F 510 PHI(L)=.1
F 512 CONTINUE
;
;      CYCLONE MODEL
;
F      DO 310 L=1,35
F      IF(L.NE.1) GO TO 301
F      DPI=DP(L)/2.
F      GO TO 302
F 301 DPI=(DP(L)+DP(L-1))/2.0
F 302 TEST=DPI/DPC
F      IF(TEST.LT.8.0) GO TO 303
F      EFFL(L)=1.0
F      EFFC(L)=1.0
F      GO TO 304
F 303 EFFL(L)=.988-1.2567*.387**(DPI/DPC)
F      EFFC(L)=.988-1.2567*.387**(DPI/DPC*.839607)
F 304 CONTINUE
F 310 CONTINUE
F      F=FCL/3600./2.2*PROX(2)*10.
F      FLOW=(FLI*.56+FAI+FCL*PROX(4)/100.+(FCL*ULT(6)/100./32.064)*Y*
F      C 80.062)/3600./2.2*1000.
F      X=0.0
F      Y=0.0
F      Z=0.0
F      DO 90 N=6,35

```

```

F      DO 89 L=1,5
F      FO(L)=FO(L)+FAC*FO(N)
F      FO(N)=FO(N)-FAC*FO(N)
F 89    CONTINUE
F 90    CONTINUE
F      FLAG1=0
F 123   DO 100 L=1,35
;
;      DIMENSIONLESS DRAG COEFFICIENT  EQ'N 3-25 PG 76 KUNII & LEV.
;
F      CDREP(L)=4.0*G*DP(L)**3*RHOG*(RHOSL-RHOG)/3.0/MU**2
;
;      TERMINAL VELOCITY OF PARTICLES WITH SPHERICITY=.8.  FROM K&L
;      PG 77 FIG. 8
;
F      IF(CDREP(L) .GT. .544) GO TO 93
F      REP(L)=-2.0
F      KCOMP(L)=3.0E-4
F      UT(L)=.01*MU/DP(L)/RHOG
F      GO TO 96
F 93    IF(CDREP(L) .GE. 10.0) GO TO 94
F      REP(L)= (DLOG(CDREP(L))/2.30258-1.7047)/1.0397
F      GO TO 95
F 94    REP(L)=-2.608+.17561*DLOG(CDREP(L))/2.30258+
F      C 1.8001*(DABS(DLOG(CDREP(L))/2.30258))**.5
F 95    UT(L)=(10**REP(L))*MU/DP(L)/RHOG
F      IF(UT(L) .GT. UO) GO TO 97
F      KCOMP(L)=10**(-2.0556+1.18642*REP(L)+.124757*REP(L)**2
F      C -.05743*REP(L)**3)
F 96    ERCL(L)=KCOMP(L)*MU*(UO-UT(L))**2/G/DP(L)**2*SA/WL
F      GO TO 99
F 97    KCOMP(L)=0.0
F      ERCL(L)=0.0
F 99    CONTINUE
F 100   CONTINUE
F      END1=FLOW
F      END2=.0001
F      INT=(END1-END2)/2
F 105   FLOW1=END1-INT
F      SUM=0.0
F      DO 110 L=1,35
F      SUM=SUM+FO(L)*FLOW/(1.0+(WL/FLOW1/PHI(L))*ERCL(L)*(1.-EFFL(L)*R))
F 110   CONTINUE
F      ERR=SUM-FLOW1
F      IF (DABS(ERR) .LT. 1E-6) GO TO 116
F      IF (INT .LT. 1E-6) GO TO 116
F      IF (ERR .GT. 0.0) GO TO 115
F      END1=END1-INT
F      INT=INT/2
F      GO TO 105
F 115   END2=END2+INT
F      INT=INT/2
F      GO TO 105
F 116   FLOW2=FLOW-FLOW1

```

```

F      DO 170 L=1,35
F      F1(L)=(F0(L)*FLOW/(1+(WL/FLOW1/PHI(L))*ERCL(L)*(1.-EFFL(L)*R)))
F      C /FLOW1
F      F2(L)=((F0(L)*FLOW)-(F1(L)*FLOW1))/FLOW2
F 170   CONTINUE
F      SUMPS=0.0
F      DO 201 L=1,35
F      SUMPS=SUMPS+F1(L)
F      IF(SUMPS.GT.0.5) GO TO 175
F 201   CONTINUE
F 175   DPMEAN=DP(L)-((DP(L)-DP(L-1))*(SUMPS-.5)/F1(L))
;      ZBAR=(6.44-2.18*THETA-.00279*TEMPP)*1E-4
F      WRITE(NHSTRY,*) ZBAR,THETA,TEMPP
F      TTEMP=(TEMPP-32.0)*5.0/9.0+273.15
F      OVER=9.5E-6*(F*3.6+FCL*(ULT(2)-PROX(2))/220.)/(U0/100.)**.93*
F      C (DPMEAN/10.)**.8*(FLOW1*3.6)**.5/THETA**2*DEXP(7000./TTEMP)/3.6
F      C *DEXP(-.3*R)
F      ZBAR=RATE*1E-4
F      WC=WB*OVER/(OVER+FLOW1)
F      MOVERF=WC/F
F      WL=WB-WC
F      IF(FLAG1.NE.0) GO TO 212
F      FLAG1=1
F      GO TO 123
F 212   AK1(1)=AK1(1)/DP(1)
F      DO 2 K=2,35
F      AK1(K)=AK1(K)/(DP(K)-DP(K-1))
F 2     CONTINUE
F      DO 10 K=1,35
;
;      DIMENSIONLESS DRAG COEFFICIENT EQ'N 3-25 PG 76 KUNII & LEV.
;
F      CDREP(K)=4.0*G*DP(K)**3*RHOG*(RHOS-RHOG)/3.0/MU**2
;
;      TERMINAL VELOCITY OF PARTICLES WITH SPHERICITY=.6. FROM K&L
;      PG 77 FIG. 8
;
F      IF(CDREP(K) .GT. .544) GO TO 3
F      KCOMP(K)=3.0E-4
F      UT(K)=.01*MU/DP(K)/RHOG
F      GO TO 6
F 3     IF(CDREP(K) .GE. 10.0) GO TO 4
F      REP(K)= (DLOG(CDREP(K))/2.30258-1.8195)/1.0397
F      GO TO 5
F 4     REP(K)=-2.7673+.17561*DLOG(CDREP(K))/2.30258+
F      C 1.8001*(DABS(DLOG(CDREP(K))/2.30258))**.5
F 5     UT(K)=(10**REP(K))*MU/DP(K)/RHOG
F      IF(UT(K) .GT. U0) GO TO 7
F      KCOMP(K)=10**(-2.0556+1.18642*REP(K)+.124757*REP(K)**2
F      C -.05743*REP(K)**3)
F 6     ERC(K)=KCOMP(K)*MU*(U0-UT(K))**2/G/DP(K)**2*SA/WC
F      GO TO 9
F 7     KCOMP(K)=0.0
F      ERC(K)=0.0

```

```

F 9      CONTINUE
F 10     CONTINUE
F 16     DO 45 L=1,35
F         TOT=0.0
F         DO 30 K=1,35
F         IF (L.NE. K) GO TO 17
F         I(L,K)=1.0
F         GO TO 29
F 17     IF (L.LT. K) GO TO 20
F         I(L,K)=0.0
F         GO TO 29
F 20     ADD=(OVER*PHI(K)/WC+(ERC(K)+ERC(K-1))/2.*(1.-(EFFC(K)+EFFC(K-1)
F C      )/2.*R))*(DP(K)-DP(K-1))
F         TOT=TOT+ADD
F         TEST=-1.0/13.39/ZBAR*TOT
F         I(L,K)=0.0
F         IF(TEST.LT.-20.0) GO TO 29
F         I(L,K)=DEXP(TEST)
F 29     CONTINUE
F 30     CONTINUE
F 45     CONTINUE
F         TOT2=0.0
F         K=1
F 50     SUM2=0.0
F         DO 55 L=1,K
F         IF(L.NE.1) GO TO 52
F         ADD=0.0
F         DO 51 N=1,20
F         ADD=ADD+.05
F         SUM2=SUM2+(ADD*DP(L)/DP(K))**3*I(L,K)*.05*DP(L)*
F C      ERC(L)*(1.-EFFC(L)*R)
F 51     CONTINUE
F         GO TO 54
F 52     ADD=0.0
F         DO 53 N=1,20
F         ADD=ADD+.05
F         SUM2=SUM2+((ADD*(DP(L)-DP(L-1))+DP(L-1))/DP(K))**3*I(L,K)*
F C      .05*(DP(L)-DP(L-1))*(ADD*(ERC(L)-ERC(L-1))+ERC(L-1))
F C      *(1.-(ADD*(EFFC(L)-EFFC(L-1))+EFFC(L-1))*R)
F 53     CONTINUE
F 54     CONTINUE
F 55     CONTINUE
F         IF(K.NE.1) GO TO 56
F         TOT2=TOT2+AK1(K)*DP(K)*SUM2
F         GO TO 57
F 56     TOT2=TOT2+AK1(K)*(DP(K)-DP(K-1))*SUM2
F 57     K=K+1
F         IF(K.LE.35) GO TO 50
F         JOVERF=TOT2/13.39/ZBAR
F         J=JOVERF*F
F         L=1
F         K2(L)=0.0
F         DO 84 K=L,35
F         ADD=0.0

```

```

F      DO 83 N=1,20
F      ADD=ADD+.05
F      IF(K.LE.1) GO TO 80
F      K2(L)=K2(L)+AK1(K)*((DP(L)-(DP(L+1)-DP(L))/2.0)/(ADD*
F      C  (DP(K)-DP(K-1))+DP(K-1)))**3*(ADD*(I(L,K)-I(L,K-1))+I(L,K-1))
F      C  *.05*(DP(K)-DP(K-1))
F      GO TO 82
F 80    K2(L)=K2(L)+AK1(K)*((DP(L)-(DP(L+1)-DP(L))/2.0)/DP(K))**3*I(L,K)
F      C  *ADD*DP(K)
F 82    CONTINUE
F 83    CONTINUE
F 84    CONTINUE
F      DO 87 L=2,35
F      K2(L)=0.0
F      DO 86 K=L,35
F      ADD=0.0
F      DO 85 N=1,20
F      AC'=ADD+.05
F      K2(L)=K2(L)+AK1(K)*((DP(L)+DP(L-1))/2.0)/(ADD*
F      C  (DP(K)-DP(K-1))+DP(K-1)))**3*(ADD*(I(L,K)-I(L,K-1))+I(L,K-1))
F      C  *.05*(DP(K)-DP(K-1))
F 85    CONTINUE
F 86    CONTINUE
F      K2(L)=K2(L)*F/WC/13.39/ZBAR
F 87    CONTINUE
F      K4(1)=ERC(1)*(1.-EFFC(1)*R)*2.0*MOVERF/JOVERF*K2(1)
F      DO 88 K=2,34
F      K4(K)=((ERC(K+1)+ERC(K-1))/2.0)*(1.-(EFFC(K)+EFFC(K+1))/2.*R)
F      C  *MOVERF/JOVERF*(K2(K+1)+K2(K-1))/2.0
F 88    CONTINUE
F      K4(35)=ERC(35)*(1.-EFFC(35)*R)*MOVERF/JOVERF*K2(35)
F 206   L=1
F      SUM1=0.0
F      SUM2=0.0
F      AK1(L)=AK1(L)*DP(L)
F      K2(L)=K2(L)*DP(L)
F      K4(L)=K4(L)*DP(L)
F      SUM1=SUM1+K2(L)
F      SUM2=SUM2+K4(L)
F      DO 209 L=2,35
F      AK1(L)=AK1(L)*(DP(L)-DP(L-1))
F      K2(L)=K2(L)*(DP(L)-DP(L-1))
F      K4(L)=K4(L)*(DP(L)-DP(L-1))
F      SUM1=SUM1+K2(L)
F      SUM2=SUM2+K4(L)
F 209   CONTINUE
F      DO 197 L=1,35
F      K2(L)=K2(L)/SUM1
F      K4(L)=K4(L)/SUM2
F 197   CONTINUE
F      WRITE(NHSTRY,250) WL,WC,RHOSL,RHOS,RHOG,UO,SA,MU
F 250   FORMAT(1X'      INPUT DATA FOR FORTRAN CODE'//
F      C  1X,'WEIGHT OF LIMESTONE IN BED      ',E8.3,' GR.'/
F      C  1X,'WEIGHT OF COAL IN BED          ',E8.3,' GR.'/

```

```

F C 1X,'DENSITY OF LIMESTONE' ,F8.3,' GR./CM**3'/
F C 1X,'DENSITY OF COAL' ,F8.3,' GR./CM**3'/
F C 1X,'DENSITY OF GAS' ,E8.3,' GR./CM**3'/
F C 1X,'SUPERFICIAL VELOCITY' ,F8.3,' CM/SEC'/
F C 1X,'BED SURFACE AREA' ,E8.3,' CM**2'/
F C 1X,'GAS VISCOSITY' ,E8.3,' GR/CM/SEC'////)
F WRITE(NHSTRY,251) FLI,FCL
F 251 FORMAT(1X' FEED FLOW RATES' '//
F C 1X,'TOTAL LIMESTONE STREAM FEED RATE' ,F8.3,' LB/HR'/
F C 1X,'COAL FEED RATE' ,F8.3,' LB/HR'////)
F K4(K)=0.0
F IF(DPMEAN.GT..05) GOTO 204
F WRITE(NHSTRY,203) DPMEAN
F 203 FORMAT(1X,'WARNING DPMEAN',F10.3,' LT .05CM IN SO2 CAPTURE EQN')
F GOTO 315
F 204 IF(DP(L).LT..1) GOTO 315
F WRITE(NHSTRY,205) DPMEAN
F 205 FORMAT(1X,'WARNING DPMEAN',F10.3,' GT 1CM IN SO2 CAPTURE EQN')
F 315 CONTINUE
F 211 OVER=OVER*3600.*2.2/1000.
F FLOW1=FLOW1*3600.*2.2/1000.
F J =J*3600.*2.2/1000.
F FLOW2=FLOW2*3600.*2.2/1000.
F WRITE(NHSTRY,210) OVER,FLOW1,J,FLOW2
F 210 FORMAT(///,1X,'TOTAL OVERFLOW COAL' ,F10.3,'LB/HR',/
F C 1X,'TOTAL OVERFLOW LIME' ,F10.3,'LB/HR',/
F C 1X,'TOTAL ELUTRIATED COAL' ,F10.3,'LB/HR',/
F C 1X,'TOTAL ELUTRIATED LIME' ,F10.3,'LB/HR')
F OUTCL=J+OVER
EXECUTE AFTER MIX1
;
FORTRAN VOLP
DEFINE CONV1 BLOCK-VAR BLOCK=DEVOL SENTENCE=CONV VARIABLE=CONV ID1=1
DEFINE CONV2 BLOCK-VAR BLOCK=DEVOL SENTENCE=CONV VARIABLE=CONV ID1=2
DEFINE CONV3 BLOCK-VAR BLOCK=DEVOL SENTENCE=CONV VARIABLE=CONV ID1=3
DEFINE CONV4 BLOCK-VAR BLOCK=DEVOL SENTENCE=CONV VARIABLE=CONV ID1=4
DEFINE CONV5 BLOCK-VAR BLOCK=DEVOL SENTENCE=CONV VARIABLE=CONV ID1=5
DEFINE FS MASS-FLOW STREAM=RAWFEED SUBSTREAM=CIPSD COMPONENT=SIO2
DEFINE FCL MASS-FLOW STREAM=RAWFEED SUBSTREAM=NCPSD COMPONENT=COAL
VECTOR-DEF PROXP COMPONENT-ATTR STREAM=RAWFEED SUBSTREAM=NCPSD &
COMPONENT=COAL ATTRIBUTE=PROXANAL
VECTOR-DEF ULTP COMPONENT-ATTR STREAM=RAWFEED SUBSTREAM=NCPSD &
COMPONENT=COAL ATTRIBUTE=ULTANAL
VECTOR-DEF SULP COMPONENT-ATTR STREAM=RAWFEED SUBSTREAM=NCPSD &
COMPONENT=COAL ATTRIBUTE=SULFANAL
F WRITE(NHSTRY,*) FS,FCL
F CONV1 = (ULTP(2)-PROXP(2))/100./(1.0 - ULTP(1)/100.)
F CONV2 = ULTP(6)/100./(1.0 - ULTP(1)/100.)
F CONV3 = ULTP(3)/100./(1.0 - ULTP(1)/100.)
F CONV4 = ULTP(4)/100./(1.0 - ULTP(1)/100.)
F CONV5 = ULTP(7)/100./(1.0 - ULTP(1)/100.)
F FS = FCL*ULTP(1)/100.+FS
F FCL = FCL*(1-ULTP(1)/100.)
F DO 101 L=1,LULTP

```



```

TOL-SPEC .01
VARY STREAM-VAR STREAM=AERSPLY VARIABLE=MASS-FLOW
LIMITS 1.0 100000.
;
DES-SPEC TEST
  DEFINE VHE STREAM-VAR STREAM=STEAM2 VARIABLE=MASS-ENTH
  SPEC VHE TO -5676.0762
  TOL-SPEC .001
  VARY STREAM-VAR STREAM=COND VARIABLE=MASS-FLOW
  LIMITS 1000.0 100000.0
;
DES-SPEC EQUAL
  DEFINE WAT1 STREAM-VAR STREAM=AERSPLY VARIABLE=MASS-FLOW
  DEFINE WAT2 STREAM-VAR STREAM=DUMMY VARIABLE=MASS-FLOW
  SPEC WAT2 TO WAT1
  TOL-SPEC .001
  VARY BLOCK-VAR BLOCK=AERSPLIT SENTENCE=FRAC VARIABLE=FRAC &
    ID1=DUMMY
  LIMITS .001 .999
*****
;
;           SEQUENCE & CONVERGENCE BLOCKS
;
*****
;
CONVERGENCE CV1 WEGSTEIN
  TEAR CRETURN
;
CONVERGENCE CV4 ONE-VAR
  SPEC TEMP
;
CONVERGENCE CV5 ONE-VAR
  SPEC EQUAL
;
CONVERGENCE CV6 ONE-VAR
  SPEC TEST
;
CONVERGENCE CV11 ONE-VAR
  SPEC COALIN
;
CONVERGENCE CV12 ONE-VAR
  SPEC LIMEIN
;
CONVERGENCE CV13 ONE-VAR
  SPEC COAL
;
CONVERGENCE CV14 ONE-VAR
  SPEC DRAIN1
;
CONVERGENCE CV15 ONE-VAR
  SPEC DRAIN2
;
SEQUENCE TOTAL SCRNL CRUSHL MIXL CV12 MULT2 (RETURN CV12) SCRNC &
  CRUSHC MIXC CV11 MULT1 (RETURN CV11) MIXTOT FDFAN &

```

WATFL MIX1 AAA VOLP DEVOL CV13 BEDHEAT (RETURN CV13) &
BEDCAL BEDSUL CV14 CV15 SEP1 PSD (RETURN CV15) &
(RETURN CV14) BEDCOOL ECONO BAGHOUSE IDFAN &
DRAINCL HTSPLIT HTMIX CV6 CV1 HOTTANK SPLIT1 DUTY1 &
CWPUMP SPLIT2 SBDCOOL PBDCOOL &
MIX2 (RETURN CV1) CRPUMP CV4 AERMIX (RETURN CV4) &
BFPUMP ECONOS BEDSPLIT BOILER (RETURN CV6) &
CV5 AERSPLIT (RETURN CV5) HEATLOSS

APPENDIX II - ASPEN COSTING INPUT FILE

```

NEW COST
;
TITLE ' STAND-ALONE COSTING '
;
DESCRIPTION " STAND-ALONE COSTING "
;
;   COSTING FOR DEAERATOR
;
CBLOCK CAER COST-HORVSSL
PARAM NVS=1 NSB=0 MAT=1 SFCT=1 AFCT=1
SIZE-INPUT DIA=6[FT] LGTH=17[FT] PRES=45[PSIA] JEFF=1.0
;
;   COSTING OF BOILER FEED PUMP
;
CBLOCK CBOILFD COST-PUMP
PARAM NPMP=1 NSB=0 PTYP=5 MTYP=2 SRSY=2 MAT=3 SFCT=1 AFCT=1
SIZE-INPUT VFW=818.125[CUFT/HR] DENS=57.52[LB/CUFT] HEAD=520.[FT-LBF/LB]
UTILITY ELEC=ELEC1
;
;   COSTING OF COOLING WATER FEED PUMPS
;
CBLOCK CCOOLFD COST-PUMP
PARAM NPMP=2 NSB=0 PTYP=3 MTYP=2 SRSY=2 MAT=3 SFCT=1 AFCT=1
SIZE-INPUT VFW=561.458[CUFT/HR] DENS=61.17[LB/CUFT] PRS=30.[PSIA]
UTILITY ELEC=ELEC1
;
;   COSTING OF COOLING WATER RETURN PUMPS
;
CBLOCK CRETURN COST-PUMP
PARAM NPMP=2 NSB=0 PTYP=3 MTYP=2 SRSY=2 MAT=3 SFCT=1 AFCT=1
SIZE-INPUT VFW=930.4166[CUFT/HR] DENS=60.99[LB/CUFT] PRS=30.[PSIA]
UTILITY ELEC=ELEC1
;
;   SPECIFICATION OF UTILITIES COST FOR STAND-ALONE COSTING
;
UTILITY ELEC1 ELECTRICITY
IN-UNITS ENG ENERGY-PRICE = '$/KWHR'
PRICE .025300 INDX=314.5 TYPE=1
;
;   ECONOMICS SECTION FOR STAND-ALONE COSTING
;
COST-SECTION ALL-CBLK
BLOCKS ALL
;
;   MATERIAL FACTORS
;
PIPM FACT=.32 WT=0
CONM FACT=.09 WT=0
STLM FACT=.017 WT=0
INTM FACT=.073 WT=0
ELEM FACT=.083 WT=0
INSM FACT=.034 WT=0
PNTM FACT=.006 WT=0

```

```

MISM FACT=.00 WT=0
;
;      LABOUR FACTORS
;
PIPL FACT=.071
CONL FACT=.071
STLL FACT=.071
INTL FACT=.071
ELEL FACT=.071
INSL FACT=.071
PNTL FACT=.071
MISL FACT=.071
;
;      ADDITIONAL INSTALLATION COST FACTORS
;
TESTING-MAT FACT=.0 TYPE=4
TESTING-LAB FACT=.002
ADD-INST-MAT FACT=.0 TYPE=4
ADD-INST-LAB FACT=.0
EQUIPMENT UNLS=.15 SPAR=.02
BLDG-MAT FACTOR=.1 TYPE=4
BLDG-LAB FACTOR=.1
;
;----SPECIFICATION OF INDICIES USED----
;
;      THE CE AND M&S INDICES ARE FOUND MONTHLY IN CHEMICAL ENGINEERING
;      MAGAZINE. THE NELSON REFINERY INDEX IS FOUND IN THE FIRST WEEK
;      EDITION OF EVERY MONTH OF THE OIL AND GAS JOURNAL.
;
COST-INDEX
CONSTR-YEAR 1984 4 ; 4TH QUARTER OF 1984
PLANT-INDEX 324.4 1 ; CE PLANT COST INDEX
EQUIP-INDEX 799.0 2 ; M & S EQUIPMENT COST INDEX - CHEMICAL P.I.
LABOR-INDEX 265.5 1 ; CE PLANT COST INDEX - CONSTRUCTION LABOR
RAWMAT-INDEX 324.4 1 ; CE PLANT COST INDEX
FUEL-INDEX 949.9 3 ; NELSON REFINERY INDEX - FUEL COST
;
ECONOMICS
EXECUTION START=1 END=1
LOCATION CODE=CANADA
;
;      CAPITAL INVESTMENT CALCULATION
;
CAPITAL-INVE ASPEN
LABOR PROD=.9 RATE=4.9 CIDX=137.2 TYPE=3 SRAT=13.2
INVENTORY RMD=0.5 PRD=3.5
LIQ-STORE STYP=3
SERV-BLDG MCF=.06 TYPE=1 LHF=.04
SERV-SYS MCF=.04 TYPE=1 LHF=.02
ADD-DIRECT MCF=.0 TYPE=1 LHF=.0
SITE-DEVELOP MCF=.02 TYPE=1 LHF=.002
FREIGHT FACT=.02
INDIRECTS FMCF=.270 FLCF=.730 PRJM=.06 ENCF=.12 &
FECEF=.08 TYPE=1

```

ADD-DEP-CST	FACT=.0 TYPE=1
CONTINGENCY	PROCESS=.20 PROJ-DEFN=.1
LAND	FACT=.02 TYPE=1
ROYALTY	FACT=.0 TYPE=1

RESULTS OF ASPEN COSTING RUN

ASPEN/SP RUN ON 7/18/86 BY THE CAPDLAB, QUEEN'S UNIVERSITY

COST-HORVSSL (CVS01): CAER

REPORT FOR COST BLOCK CAER

*** INPUT PARAMETERS ***

NUMBER OF VESSELS	
NUMBER OF STAND-BY VESSELS	
MATERIAL OF CONSTRUCTION	CARBON STEE
CAPACITY SCALE FACTOR	1.000
COST ADJUSTMENT FACTOR	1.000
INNER DIAMETER, FT	6.000
TANGENT-TO-TANGENT LENGTH, FT	17.000
VELOCITY RATIO	0.500
PRESSURE, PSIA	45.000
JOINT EFFICIENCY	1.000
CORROSION ALLOWANCE, FT	0.0

*** SIZING RESULTS ***

CALCULATED NUMBER OF VESSELS	
CALCULATED DIAMETER, FT	6.000
CALCULATED TANGENT-TO-TANGENT LENGTH, FT	17.000
TOP SHELL THICKNESS, FT	0.020
BOTTOM SHELL THICKNESS, FT	0.020
SHELL WEIGHT PER VESSEL, LB	4223.976

*** COST RESULTS ***

BASE COST OF VESSEL	\$ 15,857.0
BASE COST OF UNIT	\$ 15,857.0
ACTUAL COST OF VESSEL	\$ 15,857.0
ACTUAL COST OF UNIT	\$ 15,857.0

COST-PUMP (CPC01): CBOILFD

*** INPUT PARAMETERS ***

NUMBER OF PUMPS	
PUMP TYPE	TWO-STAGE, 3550 RPM, H.S.C
NUMBER OF STANDBY PUMPS	
MOTOR TYPE	TOTALLY ENCLOSED, FAN-COOLE
SEVERITY OF SERVICE	MODERATE SERVIC
MATERIAL OF CONSTRUCTION	304 OR 316 STAINLES
CAPACITY SCALE FACTOR	1.000
COST ADJUSTMENT FACTOR	1.000
TOTAL VOLUMETRIC FLOW, CUFT/HR	818.125
REQUIRED PUMP HEAD, FT-LBF/LB	520.000
DENSITY OF FLUID, LB/CUFT	57.520

*** ASSOCIATED UTILITES ***

UTILITY IDENTIFICATION	ELEC
UTILITY TYPE	ELECTRICIT
POWER USAGE FOR UNIT, HP	26.035

*** SIZING RESULTS ***

REQUIRED PUMP HEAD, FT-LBF/LB	520.000
VOLUMETRIC FLOW PER PUMP, CUFT/HR	818.125
PRESSURE RISE ACROSS PUMP, PSIA	207.711
MOTOR HORSEPOWER	25.000
MATERIAL OF CONSTRUCTION FACTOR	1.950
PUMP TYPE FACTOR	2.879
PUMP EFFICIENCY	0.538

*** COST RESULTS ***

BASE PUMP COST	\$ 1,304.04
BASE MOTOR COST	\$ 1,224.38
TOTAL BASE COST PER UNIT	\$ 2,528.43
TOTAL BASE COST OF 1 UNITS	\$ 2,528.43
ACTUAL COST OF PUMP	\$ 7,321.29
ACTUAL COST OF MOTOR	\$ 1,224.38
TOTAL COST PER UNIT	\$ 8,545.68
TOTAL COST OF 1 UNITS	\$ 8,545.68

COST-PUMP (CPC01): CCOOLFD

*** INPUT PARAMETERS ***

NUMBER OF PUMPS	
PUMP TYPE	ONE-STAGE, 3550 RPM, H.S.C
NUMBER OF STANDBY PUMPS	
MOTOR TYPE	TOTALLY ENCLOSED, FAN-COOLE
SEVERITY OF SERVICE	MODERATE SERVIC
MATERIAL OF CONSTRUCTION	304 OR 316 STAINLES
CAPACITY SCALE FACTOR	1.000
COST ADJUSTMENT FACTOR	1.000
TOTAL VOLUMETRIC FLOW, CUFT/HR	561.458
DENSITY OF FLUID, LB/CUFT	61.170
PRESSURE RISE, PSIA	30.000

*** ASSOCIATED UTILITES ***

UTILITY IDENTIFICATION	ELEC
UTILITY TYPE	ELECTRICIT
POWER USAGE FOR UNIT, HP	7.824

*** SIZING RESULTS ***

REQUIRED PUMP HEAD, FT-LBF/LB	100.365
VOLUMETRIC FLOW PER PUMP, CUFT/HR	802.080
PRESSURE RISE ACROSS PUMP, PSIA	30.000
MOTOR HORSEPOWER	5.000
MATERIAL OF CONSTRUCTION FACTOR	1.950
PUMP TYPE FACTOR	2.120
PUMP EFFICIENCY	0.535

*** COST RESULTS ***

BASE PUMP COST	\$ 1,140.57
BASE MOTOR COST	\$ 358.85
TOTAL BASE COST PER UNIT	\$ 1,499.42
TOTAL BASE COST OF 2 UNITS	\$ 2,998.85
ACTUAL COST OF PUMP	\$ 4,716.16
ACTUAL COST OF MOTOR	\$ 358.85
TOTAL COST PER UNIT	\$ 5,075.01
TOTAL COST OF 2 UNITS	\$ 10,150.02

COST-PUMP (CPC01): CRETURN

*** INPUT PARAMETERS ***

NUMBER OF PUMPS	
PUMP TYPE	ONE-STAGE, 3550 RPM, H.S.C
NUMBER OF STANDBY PUMPS	
MOTOR TYPE	TOTALLY ENCLOSED, FAN-COOLED
SEVERITY OF SERVICE	MODERATE SERVICE
MATERIAL OF CONSTRUCTION	304 OR 316 STAINLESS
CAPACITY SCALE FACTOR	1.000
COST ADJUSTMENT FACTOR	1.000
TOTAL VOLUMETRIC FLOW, CUFT/HR	930.416
DENSITY OF FLUID, LB/CUFT	60.990
PRESSURE RISE, PSIA	30.000

*** ASSOCIATED UTILITIES ***

UTILITY IDENTIFICATION	ELEC
UTILITY TYPE	ELECTRICITY
POWER USAGE FOR UNIT, HP	7.824

*** SIZING RESULTS ***

REQUIRED PUMP HEAD, FT-LBF/LB	100.365
VOLUMETRIC FLOW PER PUMP, CUFT/HR	802.080
PRESSURE RISE ACROSS PUMP, PSIA	30.000
MOTOR HORSEPOWER	5.000
MATERIAL OF CONSTRUCTION FACTOR	1.950
PUMP TYPE FACTOR	2.120
PUMP EFFICIENCY	0.535

*** COST RESULTS ***

BASE PUMP COST	\$ 1,140.57
BASE MOTOR COST	\$ 358.85
TOTAL BASE COST PER UNIT	\$ 1,499.42
TOTAL BASE COST OF 2 UNITS	\$ 2,998.85
ACTUAL COST OF PUMP	\$ 4,716.16
ACTUAL COST OF MOTOR	\$ 358.85
TOTAL COST PER UNIT	\$ 5,075.01
TOTAL COST OF 2 UNITS	\$ 10,150.02

APPENDIX III - FORTRAN COSTING PROGRAM

The method used here to calculate the Total Capital Investment required to build the CFB Summerside steam heating plant is described in the textbook Basic Cost Engineering by . Humphreys and Katell and unless otherwise stated all the data and equations presented in this appendix were taken from this source. An outline, in mathematical form, of this procedure and a listing of the computer program that was developed from this procedure follow.

In this costing technique the calculation of the Total Direct Cost (ie. the total cost of the material and labor used in the actual construction of the plant) requires the knowledge of the type of units used, the purchase prices of the units and the the types of material (pure gas, liquid or solid or mixed phases) the units will be processing. Using equation 1 with data from Tables 1, 2 and 3, the Direct Cost for each unit can be calculated. Summing the Direct Costs of all the units, as in equation 2, gives the Total Direct Cost of the plant.

TABLE 1 - BARE MODULE LABOR COSTS
(Given as a Percentage of the Delivered Cost of the Unit)

Type of System Temperature Pressure	Solids ≤750F	Solids ≤750F ≤150psig	- Gas >750F ≤150psig	Liquid	
				≤150psig	>150psig
Foundations	5.32	6.65	8.00	6.65	7.32
Structures	1.50	2.00	2.50	2.00	2.50
Buildings	5.00	4.00	5.00	4.00	5.00
Insulation	3.00	4.50	1.50	1.50	1.50
Instruments	0.80	2.40	2.80	1.60	2.00
Electrical	3.75	4.50	4.50	6.00	6.75
Piping	3.00	17.50	20.00	15.00	17.50
Painting	0.90	0.90	1.20	0.90	1.20
Miscellaneous	2.40	2.80	3.20	3.20	4.00
TOTAL	25.67	45.25	48.70	40.85	47.77

TABLE 2 - BARE MODULE MATERIAL COSTS
(Given as a Percentage of the Delivered Cost of the Unit)

Type of System Temperature Pressure	Solids ≤750F	Solids ≤750F ≤150psig	- Gas >750F ≤150psig	Liquid	
				≤150psig	>150psig
Foundations	4.00	5.00	6.00	5.00	5.50
Structures	3.00	4.00	5.00	4.00	5.00
Buildings	5.00	4.00	5.00	4.00	5.00
Insulation	2.00	3.00	1.00	1.00	1.00
Instruments	2.00	6.00	7.00	4.00	5.00
Electrical	5.00	6.00	6.00	8.00	9.00
Piping	6.00	35.00	40.00	30.00	35.00
Painting	0.30	0.30	0.40	0.30	0.40
Miscellaneous	3.00	3.50	4.00	4.00	5.00
TOTAL	30.30	66.80	74.40	60.30	70.90

TABLE 3 - SETTING LABOR COSTS
(Given as a Percentage of the Delivered Cost of the Unit)

ITEM	PERCENT	ITEM	PERCENT
Hoppers and Silos	15	Coal Crusher	30
Compressors	35	Baghouses	32
Conveyors	25	Pumps	30
F-B Boilers	30	Coal Screen	20
Vibratory Feeders	15	Tanks	20
Bunkers and Bins	15	Bucket Elevators	40
Tramp Iron Magnet	25	Screw Feeders	25

$$\left(\begin{array}{c} \text{Direct Cost} \\ \text{of a Unit} \end{array} \right) = \left(\begin{array}{c} \text{Delivered Cost} \\ \text{of Unit} \end{array} \right) * \left[1.0 + \left(\frac{\text{Setting Labor Costs} \\ \text{for Unit (see Table 3)}}{100} \right) + \right.$$

$$\left. \left(\frac{\text{Total Bare Module Labor Costs}}{100} \right) + \left(\frac{\text{Total Bare Module Material Costs}}{100} \right) \right] \quad (1)$$

$$\text{Where: } \left(\begin{array}{c} \text{Delivered Cost} \\ \text{of Unit} \end{array} \right) = 1.081 * (\text{Purchased Price}) \quad (\text{Guthrie, 1969}) \quad (1a)$$

$$\left(\begin{array}{c} \text{Total Direct} \\ \text{Cost of} \\ \text{Plant} \end{array} \right) = \sum_{\text{All Units}} \left(\begin{array}{c} \text{Direct Cost} \\ \text{of Unit} \end{array} \right) \quad (2)$$

Field Indirect Costs, as calculated in equation 3, include the cost of supervisory, office and clerical personnel directly involved with the project.

$$\left(\begin{array}{c} \text{Field} \\ \text{Indirect} \\ \text{Costs} \end{array} \right) = \sum_{\text{All Units}} \left(\frac{\text{Delivered Cost}}{2} \right) * \left(\frac{\text{Total Bare Module Labor} \\ \text{Cost for Unit (see Table 1)}}{100} \right) \quad (3)$$

Total Construction Cost is the sum of the Total Direct Cost and the Field Indirect Costs (equation 4).

$$\left(\begin{array}{c} \text{Total} \\ \text{Construction} \\ \text{Cost} \end{array} \right) = \left(\begin{array}{c} \text{Total Direct} \\ \text{Cost of} \\ \text{Plant} \end{array} \right) + \left(\begin{array}{c} \text{Field} \\ \text{Indirect} \\ \text{Costs} \end{array} \right) \quad (4)$$

The engineering and front office support costs are calculated next in equations 5 and 6. Summation of the Total Construction Cost and these two items produces Subtotal1 (equation 7).

$$(\text{Engineering}) = 0.10 * (\text{Total Construction Cost}) \quad (5)$$

$$(\text{Overhead \& Administration}) = 0.075 * (\text{Total Construction Cost}) \quad (6)$$

$$(\text{Subtotal1}) = \left(\frac{\text{Total}}{\text{Construction Cost}} \right) + (\text{Engineering}) + \left(\frac{\text{Overhead and Administration}}{\text{Administration}} \right) \quad (7)$$

A Contingency fund is included to allow for possible redesign of equipment or an escalation in labor costs (equation 8). Summation of the Contingency fund and Subtotal1 produces Subtotal2 (equation 9).

$$(\text{Contingency}) = 0.20 * (\text{Subtotal1}) \quad (8)$$

$$(\text{Subtotal2}) = (\text{Contingency}) + (\text{Subtotal1}) \quad (9)$$

The fees paid to the engineering and installation organizations for their involvement in the operation is estimated in equation 10. Summation of the Construction Fees and Subtotal2 gives the Fixed Capital Investment of the project (equation 11)

$$(\text{Construction Fees}) = 0.075 * (\text{Subtotal2}) \quad (10)$$

$$\left(\begin{array}{l} \text{Fixed Capital} \\ \text{Investment} \end{array} \right) = (\text{Construction Fees}) + (\text{Subtotal2}) \quad (11)$$

Working Capital is also required to meet the cost of one month's operation of the plant. This is estimated in equation 12. The Total Capital Investment of the plant can then be calculated by summing the required Working Capital and the Fixed Capital Investment (equation 13).

$$\left(\begin{array}{l} \text{Working} \\ \text{Capital} \end{array} \right) = 0.10 * \left(\begin{array}{l} \text{Fixed Capital} \\ \text{Investment} \end{array} \right) \quad (\text{Guthrie, 1969}) \quad (12)$$

$$\left(\begin{array}{l} \text{Total Capital} \\ \text{Investment} \end{array} \right) = \left(\begin{array}{l} \text{Fixed Capital} \\ \text{Investment} \end{array} \right) + \left(\begin{array}{l} \text{Working} \\ \text{Capital} \end{array} \right) \quad (13)$$

Thus the Total Capital Investment required to build the CFB Summerside steam heating plant is calculated. A listing of the program developed to carry out these computations starts on the following page.


```

9      DO 10 J=1,NEQUIP
C      COST(J,1)=UCOST(J)*CAP(J)**(SIZE(X(J)))*(CAP(J)**SIZE(X2(J))**
C      (ALOG10(CAP(J)))*MS1985/DEX(J)*1.081*1.35
C      COST(J,1)=UCOST(J)*CAP(J)**(SIZE(X(J)))*(CAP(J)**SIZE(X2(J))**
C      (ALOG10(CAP(J)))*690.2/DEX(J)*1.081*1.1922
10     CONTINUE
      DO 1001 I=1,NEQUIP
      COST(I,2)=COST(I,1)*PERCEN(I)
      COST(I,3)=COST(I,1)+COST(I,2)
      SUB(1)=SUB(1)+COST(I,1)
      SUB(2)=SUB(2)+COST(I,2)
      SUB(3)=SUB(3)+COST(I,3)
      IF(TYPE(I).EQ.0) GOTO 200
      IF(TYPE(I).EQ.1) GOTO 400
      IF(TYPE(I).EQ.2) GOTO 600
      IF(TYPE(I).EQ.3) GOTO 800
      IF(TYPE(I).EQ.4) GOTO 900
      WRITE(6,11)
11     FORMAT(1X,'TYPE CONSTANT NOT VALID. CHECK INPUT DATA')
      GOTO 2002
200    DO 210 J=1,9
      PECOST(J,1)=PECOST(J,1)+COST(I,1)*PEMATS(J)
      PECOST(J,2)=PECOST(J,2)+COST(I,1)*PEMATS(J)*PELAB(J)
      PECOST(J,3)=PECOST(J,3)+COST(I,1)*PEMATS(J)*(1.0+PELAB(J))
210    CONTINUE
      GOTO 1001
400    DO 410 J=1,9
      PECOST(J,1)=PECOST(J,1)+COST(I,1)*PEMASG(J)
      PECOST(J,2)=PECOST(J,2)+COST(I,1)*PEMASG(J)*PELAB(J)
      PECOST(J,3)=PECOST(J,3)+COST(I,1)*PEMASG(J)*(1.0+PELAB(J))
410    CONTINUE
      GOTO 1001
600    DO 610 J=1,9
      PECOST(J,1)=PECOST(J,1)+COST(I,1)*PEMATG(J)
      PECOST(J,2)=PECOST(J,2)+COST(I,1)*PEMATG(J)*PELAB(J)
      PECOST(J,3)=PECOST(J,3)+COST(I,1)*PEMATG(J)*(1.0+PELAB(J))
610    CONTINUE
      GOTO 1001
800    DO 810 J=1,9
      PECOST(J,1)=PECOST(J,1)+COST(I,1)*PEMATL(J)
      PECOST(J,2)=PECOST(J,2)+COST(I,1)*PEMATL(J)*PELAB(J)
      PECOST(J,3)=PECOST(J,3)+COST(I,1)*PEMATL(J)*(1.0+PELAB(J))
810    CONTINUE
      GOTO 1001
900    DO 910 J=1,9
      PECOST(J,1)=PECOST(J,1)+COST(I,1)*PEMALH(J)
      PECOST(J,2)=PECOST(J,2)+COST(I,1)*PEMALH(J)*PELAB(J)
      PECOST(J,3)=PECOST(J,3)+COST(I,1)*PEMALH(J)*(1.0+PELAB(J))
910    CONTINUE
      GOTO 1001
1001   CONTINUE
      DO 1020 I=1,3
      DO 1010 J=1,9
      TDIR(I)=TDIR(I)+PECOST(J,I)

```

```

1010      CONTINUE
          TDIR(I)=TDIR(I)+SUB(I)
1020      CONTINUE
          TCOST(1)=.5*TDIR(2)
          TCOST(2)=TCOST(1)+TDIR(3)
          TCOST(3)=TCOST(2)*.1
          TCOST(4)=TCOST(2)*.075
          TCOST(5)=TCOST(2)+TCOST(3)+TCOST(4)
          TCOST(6)=TCOST(5)*.20
          TCOST(7)=TCOST(5)+TCOST(6)
          TCOST(8)=TCOST(7)*.075
          TCOST(9)=TCOST(8)+TCOST(7)
          TCOST(10)=TCOST(9)*.1
          TCOST(11)=TCOST(9)+TCOST(10)
          WRITE(6,1200)
1200      FORMAT(////,T20,'ECONOMIC EVALUATION',//
+          T14,'CFB SUMMERSIDE - ASPEN SIMULATION'///
+          T25,'INPUT DATA'//)
          WRITE(6,1210) NUMBLR,COALFL,LIMEFL,STMFL,MAKEUP,NUMOP
1210      FORMAT(1X,'OPERATING CONDITIONS',/
C          T5,'NUMBER OF BOILERS OPERATING',T50,F10.1,/
C          T5,'COAL FEED RATE PER BOILER (LB/HR)',T50,F10.1,/
C          T5,'LIMESTONE FEED RATE PER BOILER (LB/HR)',T50,F10.1,/
C          T5,'STEAM PRODUCTION RATE PER BOILER (LB/HR)',T50,F10.1,/
C          T5,'MAKEUP WATER FEED RATE PER BOILER (LB/HR)',T50,F10.1,/
C          T5,'NUMBER OF OPERATORS',T50,F10.1,/
          WRITE(6,1211) FDDRAW,IDDRAW,CWDRAW,CRDRAW,BFDRW,CLHAND,LMHAND
1211      FORMAT(1X,'ELECTRICITY CONSUMPTION PER BOILER (WATTS)',/
C          T5,'FORCED DRAFT FAN',T50,F10.1,/
C          T5,'INDUCED DRAFT FAN',T50,F10.1,/
C          T5,'COOLING WATER PUMP',T50,F10.1,/
C          T5,'CONDENSATE RETURN PUMP',T50,F10.1,/
C          T5,'BOILER FEED PUMP',T50,F10.1,/
C          T5,'COAL HANDLING SYSTEM',T50,F10.1,/
C          T5,'LIMESTONE HANDLING SYSTEM',T50,F10.1,/
          WRITE(6,1212) OPHRS,CLCOST,LMCOST,MUCOST,ELCOST,OPSAI
1212      FORMAT(1X,'ECONOMIC PARAMETERS',/
C          T5,'OPERATING HOURS (90% AVAILABILITY)',T50,F10.1,/
C          T5,'COAL COST (DOLLARS/TON)',T50,F10.1,/
C          T5,'LIMESTONE COST (DOLLARS/TON)',T50,F10.1,/
C          T5,'MAKEUP WATER COST (DOLLARS/1000 LBS)',T50,F10.4,/
C          T5,'ELECTRICITY COST (DOLLARS/KW-HR)',T50,F10.4,/
C          T5,'OPERATOR SALARY (DOLLARS/MAN-YEAR)',T50,F10.1,/
          WRITE(6,1502)
1502      FORMAT('1',///,T20,'FIXED CAPITAL INVESTMENT',///
+          T10,'-----')
+          T35,'COST(DOLLARS)',T50,' TOTAL COST'/
+          T16,'ITEM',T30,' MATERIAL',T40,' LABOUR',T51,' (DOLLARS)'/
+          T10,'-----')
          DO 1510 I=1,NEQUIP
          WRITE(6,1504) SPNAME(I),(COST(I,J),J=1,3)
1504      FORMAT(T15,A8,T30,F10.1,T40,F10.1,T50,F11.1)
1510      CONTINUE
          WRITE(6,1505) (SUB(J),J=1,3)

```

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1505  FORMAT(T30,'-----'/T10,'SUBTOTAL ONE'
+    T30,F10.1,T40,F10.1,T50,F11.1//)
    WRITE(6,1506) ((PECOST(I,J),J=1,3),I=1,9)
1506  FORMAT(T10,'FOUNDATIONS',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'STRUCTURES',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'BUILDINGS',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'INSULATION',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'INSTRUMENTAL',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'ELECTRAL',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'PIPING',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'PAINTING',T30,F10.1,T40,F10.1,T50,F11.1/
+    T10,'MISCELLANEOUS',T30,F10.1,T40,F10.1,T50,F11.1/)
    WRITE(6,1507) (TDIR(J),J=1,3)
1507  FORMAT(T30,'-----',/
+    T10,'TOTAL DIRECT',T30,F10.1,T40,F10.1,T50,F11.1,/)
    WRITE(6,1508) (TCOST(J),J=1,11)
1508  FORMAT(T10,'FIELD INDIRECT',T50,F11.1/T50,'-----',/
+    T10,'TOTAL CONSTRUCTION',T50,F11.1/T10,'ENGINEERING',T50,F11.1/
+    T10,'OVERHEAD AND ADMINISTRATION',T50,F11.1/T50,'-----'/
+    T20,'SUBTOTAL TWO ',T50,F11.1/T10,'CONTINGENCY',T50,F11.1/
+    T50,'-----'/T20,'SUBTOTAL THREE',T50,F11.1/
+    T10,'FEE',T50,F11.1/T50,'-----'/
+    T10,'TOTAL FIXED CAPITAL INVESTMENT',T50,F11.1/
+    T10,'WORKING CAPITAL',T50,F11.1/T50,'-----'/
+    T10,'TOTAL CAPITAL INVESTMENT',T50,F11.1/
+    T50,'=====')
POWER=(FDDRAW+IDDRAW+CWDRAW+CRDRAW+BFDRAW+CLHAND+LMHAND)*OPHRS
C    *NUMBLR/1000.0
    CPOWER=POWER*ELCOST*NRFUEL/832.2
    CRAWCL=COALFL*NUMBLR*OPHRS*CLCOST/2000.0*NRFUEL/832.2
    CRAWLM=LIMEFL*NUMBLR*OPHRS*LMCOST/2000.0*NRFUEL/832.2
    CMUWAT=MAKEUP*NUMBLR*OPHRS*MUCOST/1000.0*NRFUEL/832.2
    CLABR =NUMOP*OPSAL*CESAL/382.6
    FRING = .3*CLABR
    ADMIN = .4*CLABR
    OPSUP = .06*CLABR
    MNTSUP= .012*TCOST(11)
    TAXES = .03*TCOST(11)
    INSUR = .005*TCOST(11)
    OTHER = .02*TCOST(11)
C    CAPIT = TCOST(11)*INT/((1.0-(1.0/(1+INT)**29))-4*INT)
    CAPIT = 0.0
    TOTAL =CPOWER+CRAWCL+CRAWLM+CMUWAT+CLABR+FRING+ADMIN+OPSUP+
C        MNTSUP+TAXES+INSUR+OTHER+CAPIT
    PROD =STMFL*NUMBLR*1.14624*.29307*OPHRS*ELCOST*NRFUEL/832.2
    WRITE(6,1600) CPOWER,CRAWCL,CRAWLM,CMUWAT,CLABR,
+    FRING,ADMIN,OPSUP,MNTSUP,TAXES,INSUR,CAPIT,OTHER,TOTAL
1600  FORMAT('1',///T20,'ECONOMIC EVALUATION',///
+    1X,T10,'OPERATING COSTS - FBC HEATING SYSTEM',//
+    T5,'ELECTRICITY',T40,F10.1,/
+    T5,'FEED COAL',T40,F10.1,/
+    T5,'FEED LIMESTONE',T40,F10.1,/
+    T5,'MAKEUP WATER',T40,F10.1,/
+    T5,'LABOUR',T40,F10.1,/

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+ T5,'FRINGE BENEFITS',T40,F10.1,/
+ T5,'ADMINISTRATION',T40,F10.1,/
+ T5,'OPERATING SUPPLIES',T40,F10.1,/
+ T5,'MAINTENANCE SUPPLIES',T40,F10.1,/
+ T5,'TAXES',T40,F10.1,/
+ T5,'INSURANCE',T40,F10.1,/
+ T5,'LOAN REPAYMENT',T40,F10.1,/
+ T5,'OTHER',T40,F10.1,/T39,'-----',/
+ T15,'TOTAL OPERATING COST',T39,F11.1,/T39,'=====',//)
WRITE(6,1603) PROD,PROD
1603 FORMAT(T10,'OPERATING COSTS - ELECTRIC HEATING SYSTEM',//
+ T5,'ELECTRICITY',T40,F10.1,/T39,'-----',/
+ T15,'TOTAL OPERATING COST',T39,F11.1,/T39,'=====',//)
TOTHYD=PROD*((1.0-(1.0/(1.0+INT)**29))/INT)
TOTPLT=PROD*((1.0-(1.0/(1.0+INT)**4))/INT)+
C CAPIT*((1.0-(1.0/(1.0+INT)**29))/INT)+
C (TOTAL-CAPIT)*((1.0-(1.0/(1.0+INT)**25))/INT)/(1.0+INT)**4
DIFF=TOTHYD-TOTPLT
WRITE(6,1604) DIFF
1604 FORMAT(T5,'TOTAL SAVINGS OVER 25 YEAR LIFE OF PLANT',F14.1)
2002 STOP
END

```

APPENDIX IV - FORTRAN COSTING PROGRAM OUTPUT

ECONOMIC EVALUATION
CFB SUMMERSIDE - ASPEN SIMULATION

INPUT DATA

OPERATING CONDITIONS

NUMBER OF BOILERS OPERATING	2.0
COAL FEED RATE PER BOILER (LB/HR)	4200.0
LIMESTONE FEED RATE PER BOILER (LB/HR)	1153.0
STEAM PRODUCTION RATE PER BOILER (LB/HR)	38382.0
MAKEUP WATER FEED RATE PER BOILER (LB/HR)	5396.0
NUMBER OF OPERATORS	25.0

ELECTRICITY CONSUMPTION PER BOILER (WATTS)

FORCED DRAFT FAN	101320.0
INDUCED DRAFT FAN	25367.0
COOLING WATER PUMP	1581.0
CONDENSATE RETURN PUMP	339.0
BOILER FEED PUMP	14173.0
COAL HANDLING SYSTEM	4478.9
LIMESTONE HANDLING SYSTEM	343.9

ECONOMIC PARAMETERS

OPERATING HOURS (90% AVAILABILITY)	7884.0
COAL COST (DOLLARS/TON)	25.0
LIMESTONE COST (DOLLARS/TON)	36.0
MAKEUP WATER COST (DOLLARS/1000 LBS)	0.0072
ELECTRICITY COST (DOLLARS/KW-HR)	0.0850
OPERATOR SALARY (DOLLARS/MAN-YEAR)	23700.0

FIXED CAPITAL INVESTMENT

ITEM	COST(DOLLARS)		TOTAL COST (DOLLARS)
	MATERIAL	LABOUR	
CHS-BE1	14191.1	5676.4	19867.5
CHS-BE2	24216.5	9686.6	33903.1
CHS-BE3	20191.6	8076.6	28268.2
LHS-BE2	18880.4	7552.2	26432.6
LHS-BE3	17165.1	6866.0	24031.1
CHS- C2	7437.9	1859.5	9297.4
CHS- C5	4604.6	1151.2	5755.8
TIMAGNT	4591.1	1147.8	5738.8
CHS- F2	4275.6	1068.9	5344.5
CHS- F3	4275.6	1068.9	5344.5
LHS- C1	14075.0	3518.7	17593.7
CHS- F1	5360.0	1340.0	6700.0
LHS- F1	5360.0	1340.0	6700.0
LHS- F2	4584.5	1146.1	5730.6
SCRCONV	1496.0	374.0	1870.0
CLCRUSH	58545.1	17563.5	76108.6
CHS-SC1	9401.2	1880.2	11281.4
CSBUNK1	1131.6	169.7	1301.4
CSBUNK2	1131.6	169.7	1301.4
CBIN- 1	290.2	43.5	333.7
CRECHOP	1131.6	169.7	1301.4
LSBUNK1	290.2	43.5	333.7
LRECHOP	181.1	27.2	208.3
LBIN- 1	1490.9	223.6	1714.5
ARCOMP1	10657.0	3729.9	14386.9
ARCOMP2	10657.0	3729.9	14386.9
ASHSILO	3171.3	475.7	3647.0
FABFIL1	42049.2	13455.7	55505.0
BFPMP1	7483.3	2245.0	9728.3
CWPMP1	4198.0	1259.4	5457.4
CWPMP2	4198.0	1259.4	5457.4
CRPMP1	4198.0	1259.4	5457.4
CRPMP2	4198.0	1259.4	5457.4
DEAERAT	22970.1	4594.0	27564.1
GENERAT	14593.5	0.0	14593.5
BOILER1	2626832.0	788049.6	3414881.0
ASHSYS	28971.5	9270.9	38242.4
CHS-BE4	20191.6	8076.6	28268.2
CHS-BE5	12645.1	5058.1	17703.2
LHS-BE4	17165.1	6866.0	24031.1
CHS- C3	8501.5	2125.4	10626.8
CHS- C4	4754.0	1188.5	5942.5
CHS- C6	4604.6	1151.2	5755.8
CHS- C7	4638.1	1159.5	5797.7
CHS- C8	5636.1	1409.0	7045.1

CHS- F4	4275.6	1068.9	5344.5
CHS- F5	4275.6	1068.9	5344.5
LHS- F3	4584.5	1146.1	5730.6
CSBUNK3	1131.6	169.7	1301.4
CSBUNK4	1131.6	169.7	1301.4
CBIN- 2	290.2	43.5	333.7
LBIN- 2	1490.9	223.6	1714.5
ARCOMP3	10657.0	3729.9	14386.9
FABFIL2	42049.2	13455.7	55505.0
BFPMP2	7483.3	2245.0	9728.3
CWPMP3	4198.0	1259.4	5457.4
CRPMP3	4198.0	1259.4	5457.4
BOILER2	2626832.0	788049.6	3414881.0

SUBTOTAL ONE	5799196.0	1743675.0	7542872.0
FOUNDATIONS	312960.8	416237.9	729199.4
STRUCTURES	281631.5	140815.3	422447.4
BUILDINGS	287676.2	287676.2	575353.4
INSULATION	64298.3	96447.5	160745.4
INSTRUMENTAL	280614.4	112245.9	392859.8
ELECTRICAL	503951.3	377963.2	881915.3
PIPING	1928795.0	964397.6	2893182.0
PAINTING	22666.2	67998.7	90664.9
MISCELLANEOUS	280410.9	224328.6	504739.9

TOTAL DIRECT	9762199.0	4431783.0	14193975.0
FIELD INDIRECT			2215891.0

TOTAL CONSTRUCTION			16409866.0
ENGINEERING			1640986.0
OVERHEAD AND ADMINISTRATION			1230739.0

SUBTOTAL TWO			19281584.0
CONTINGENCY			3856316.0

SUBTOTAL THREE			23137888.0
FEE			1735341.0

TOTAL FIXED CAPITAL INVESTMENT			24873216.0
WORKING CAPITAL			2487322.0

TOTAL CAPITAL INVESTMENT			27360528.0
=====			

ECONOMIC EVALUATION

OPERATING COSTS - FBC HEATING SYSTEM

ELECTRICITY	197828.7
FEED COAL	827819.8
FEED LIMESTONE	327248.7
MAKEUP WATER	612.6
LABOUR	592499.9
FRINGE BENEFITS	177749.9
ADMINISTRATION	236999.9
OPERATING SUPPLIES	35550.0
MAINTENANCE SUPPLIES	328326.2
TAXES	820815.8
INSURANCE	136802.6
LOAN REPAYMENT	6803050.0
OTHER	547210.5

TOTAL OPERATING COST 11032508.0
=====

OPERATING COSTS - ELECTRIC HEATING SYSTEM

ELECTRICITY	17281008.0
TOTAL OPERATING COST	17281008.0

TOTAL SAVINGS OVER 25 YEAR LIFE OF PLANT 10482272.0

APPENDIX V - THERMODYNAMIC CONSTANTS FOR THE GASES AND SOLIDS

ASPEN PURE COMPONENT DATA FOR GASES

COMPONENT: SULFUR-DIOXIDE

ALIAS: O2S

NAME	SRCODE	REVDAT	NOE	VALUES
MW	1	04/23/86	1	0.640630D+02
TFP	1	04/23/86	1	0.197700D+03
TB	1	04/23/86	1	0.263000D+03
TC	1	04/23/86	1	0.430800D+03
PC	1	04/23/86	1	0.788308D+07
VC	1	04/23/86	1	0.121766D+00
ZC	1	04/23/86	1	0.268000D+00
CPIG	1	04/23/86	6	0.238522D+05, 0.669888D+02, -0.496136D-01, 0.132805D-04, 0.0 0.0
DHFORM	1	04/23/86	1	-0.297053D+09
DGFORM	1	04/23/86	1	-0.300361D+09

COMPONENT: NITROGEN-DIOXIDE

ALIAS: NO2

NAME	SRCODE	REVDAT	NOE	VALUES
MW	1	04/23/86	1	0.460060D+02
TFP	1	04/23/86	1	0.261900D+03
TB	1	04/23/86	1	0.294300D+03
TC	1	04/23/86	1	0.431400D+03
PC	1	04/23/86	1	0.101325D+08
VC	1	04/23/86	1	0.169908D+00
ZC	1	04/23/86	1	0.480000D+00
CPIG	1	04/23/86	6	0.242332D+05, 0.483575D+02, -0.208084D-01, 0.293076D-06, 0.0 0.0
DHFORM	1	04/23/86	1	0.338712D+08
DGFORM	1	04/23/86	1	0.520001D+08

COMPONENT: OXYGEN

ALIAS: O2

NAME	SRCODE	REVDAT	NOE	VALUES
MW	1	04/23/86	1	0.319990D+02
TFP	1	04/23/86	1	0.544000D+02
TB	1	04/23/86	1	0.902000D+02
TC	1	04/23/86	1	0.154600D+03
PC	1	04/23/86	1	0.504598D+07
VC	1	04/23/86	1	0.733611D-01
ZC	1	04/23/86	1	0.288000D+00
CPIG	1	04/23/86	6	0.281060D+05, -0.368020D-02, 0.174590D-01, -0.106512D-04, 0.0 0.0
DHFORM	1	04/23/86	1	0.0
DGFORM	1	04/23/86	1	0.0

ASPEN PURE COMPONENT DATA FOR GASES

COMPONENT: CARBON-DIOXIDE

ALIAS: CO2

NAME	SRCODE	REVDATE	NOE	VALUES
MW	1	04/23/86	1	0.440100D+02
TFP	1	04/23/86	1	0.216600D+03
TB	1	04/23/86	1	0.194700D+03
TC	1	04/23/86	1	0.304200D+03
PC	1	04/23/86	1	0.737646D+07
VC	1	04/23/86	1	0.939446D-01
ZC	1	04/23/86	1	0.274000D+00
CPIG	1	04/23/86	6	0.197952D+05, 0.734365D+02, -0.560194D-01, 0.171533D-04, 0.0 0.0
DHFORM	1	04/23/86	1	-0.393769D+09
DGFORM	1	04/23/86	1	-0.394648D+09

COMPONENT: NITROGEN

ALIAS: N2

NAME	SRCODE	REVDATE	NOE	VALUES
MW	1	04/23/86	1	0.280130D+02
TFP	1	04/23/86	1	0.633000D+02
TB	1	04/23/86	1	0.774000D+02
TC	1	04/23/86	1	0.126200D+03
PC	1	04/23/86	1	0.339439D+07
VC	1	04/23/86	1	0.896408D-01
ZC	1	04/23/86	1	0.290000D+00
CPIG	1	04/23/86	6	0.311498D+05, -0.135652D+02, 0.267955D-01, -0.116812D-04, 0.0 0.0
DHFORM	1	04/23/86	1	0.0
DGFORM	1	04/23/86	1	0.0

COMPONENT: WATER

ALIAS: H2O

NAME	SRCODE	REVDATE	NOE	VALUES
MW	1	04/23/86	1	0.180150D+02
TFP	1	04/23/86	1	0.273200D+03
TB	1	04/23/86	1	0.373200D+03
TC	1	04/23/86	1	0.647300D+03
PC	1	04/23/86	1	0.220483D+08
VC	1	04/23/86	1	0.558953D-01
ZC	1	04/23/86	1	0.229000D+00
CPIG	1	04/23/86	6	0.337381D+05, -0.701756D+01, 0.272961D-01, -0.166465D-04, 0.429761D-08, -0.416961D-12,
DHFORM	1	04/23/86	1	-0.241997D+09
DGFORM	1	04/23/86	1	-0.228767D+09

ASPEN PURE COMPONENT DATA FOR SOLIDS

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PROP-LIST MW 1/ DHSFRM 1/ DGSFRM 1
PVAL CAO 56.08/ -.64879E9/ -.603E9
PVAL CASO4 136.14/ -1.4585E9/ -1.297E9
PVAL CACO3 100.09/ -1.2317E9/ -1.134E9
PVAL SIO2 60.08/ -.84833E9/ -.797E9
    
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PROP-LIST CPSP01 1
PVAL CAO 41.9E3 20.3 0. 0. -452.E6 273. 2000.
PVAL CASO4 77.5E3 92.0 0. 0. -665.E6 273. 2000.
PVAL CACO3 82.4E3 49.8 0. 0. -1.29E9 273. 2000.
PVAL SIO2 27.7E3 11.2 0. 0. -2.19E9 273. 2000.
    
```

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PROP-LIST VSPOLY 1
PVAL CAO 1.69E-2 0. 0. 0. 0. 0. 2000.
PVAL CASO4 4.60E-2 0. 0. 0. 0. 0. 2000.
PVAL CACO3 3.57E-2 0. 0. 0. 0. 0. 2000.
PVAL SIO2 1.21E-2 0. 0. 0. 0. 0. 2000.
    
```